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SEQUENCING IN FRONTAL LOBE PATIENTS

Connie Della Malva

Thesis presented to the School of Graduate Studies of the University of Ottawa in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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ABSTRACT

An experimental neuropsychological study was undertaken to investigate whether frontal damage selectively affects the ability to carry out sequencing tasks. Thirteen patients, assigned to an Anterior Group on the basis of locus of brain lesion, were compared to nine patients assigned to a Posterior Group. Each of these groups was compared to a Normal Control Group, matched f age, sex and level of education, on two sequencing tasks.

In the first, Increasing Span Task, subjects were required to organize sequences of increasing length. Verbal and pictorial subtests, consisting of four, six, nine and twelve unit sequences, were presented separately. The second, Capture Error Task, was designed to assess sequencing performance on tasks where a potential for capture errors exists. A capture error, in this study, was defined as the incorrect successive pairing of two items which tend to be frequently and routinely associated with one another but which, in the context of the present task, should be separated and used in a less characteristic way. The potential for a capture error was created by presenting a series of six unit sequences in which a special association existed between two successive units; this association was sometimes valid (i.e., the units should remain together in the final solution)

and sometimes invalid (i.e., the units should be taken apart and used separately in the final solution). Twenty verbal sequences and twelve pictorial sequences were administered separately in two subtests.

The results on the Increasing Span Task showed that while neither Anterior nor Posterior groups had difficulty organizing short (4 unit) sequences, subjects in the Anterior group were particularly sensitive to sequencing tasks at normal span and beyond. The results of the Capture Error Task showed that the Anterior group differed from their Control group and from the Posterior group in their ability to arrange sequences correctly when a potential for capture errors was present. The theoretical implications of these results for the role of the frontal lobes in behavior are discussed.

INTRODUCTION

Dysfunction of the frontal lobes is reflected in a number of relatively specific behavioral manifestations. While a survey of the literature shows that authors have traditionally insisted on a concept of 'frontal-lobe syndrome', one single characteristic picture is not supported by clinical or experimental evidence (Damasio, 1979). It is now known that the frontal lobes are not to be looked upon as homogenous structures, since they include regions which differ in structure and function. Gradually, the symptoms of frontal damage are being fractioned into partial disorders and this area is now viewed as a mosaic of interconnected functional units, each subserving a different aspect of behavior (Brown, 1985). Input from cognitive psychology, limited until recently, has helped to replace unitary concepts with component theories.

Evidence from clinical observations of patients and animal experimentation suggests that frontal lobe lesions affect the ability to plan and organize behavior and activities. As a result, some attention has recently been turned to one aspect of such abilities, the capacity to carry out sequences of responses. Studies have begun to examine the effects of

frontal pathology on 'sequencing' ability. Nonetheless, there has been only initial emphasis on integrating new concepts of frontal lobe function, its differentiation and specialization, in the study of sequencing ability.

This study addresses the question of sequencing ability in patients with focal brain lesions. The research is presented in four major parts. The first section presents a selected review of the literature. The methodology section details the subjects and experimental procedures. The results section follows, enumerating the significant differences. Finally in the discussion section, the implications of the findings in relation to the literature, theory and clinical relevance are explored.

Review of the Literature

This first section presents the background for the experimental study. In the first part, advances in our knowledge of the structure and function of the frontal lobes are presented, with particular emphasis on outlining some of the specific conditions which appear to require their input in behavior. To achieve this, evidence from clinical and animal studies will be selectively outlined. Advances in the study of anatomical

and functional differences of the frontal lobes will also be presented. Finally, an attempt will be made to integrate new concepts arising from cognitive theories with evidence from neuropsychological studies. The second portion of this section more directly addresses questions about sequencing ability and the frontal lobes in light of the general overview provided. Evidence from studies with animals and humans will be reviewed. The questions arising from existing data will be analyzed and a rationale will be provided for the present study.

An Historical Overview

Historically, the frontal lobes have been linked with the highest level of intellectual abilities and behavior. Early empirical research investigating the functions of the frontal lobes, however, was controversial. Some researchers reported a number of specific deficits; others tried to interpret impairments in terms of one single concept; still others argued that no deficits existed (Meyer, 1960). Teuber (1964) characterized this problem as the "riddle of the frontal lobes". Lack of consensus regarding the specific dysfunctions which underlie frontal deficits existed both in the early animal and human literature.

Early experimentation with animals revealed alterations and disintegration in behavior. Bianchi (1895) reported that dogs with bifrontal excision no longer moved purposefully or behaved selectively but, rather, engaged in motor automatisms. He postulated that the frontal lobes perform an integrative function. With their removal, behavior loses its organized character and becomes fragmented and unsubordinated to a common synthesis, ceasing to adapt itself to new conditions. Bianchi (1922) further illustrated the effect of large frontal lesions in the monkey. He observed that prior to surgery monkeys would jump onto a window ledge to call out to companions. Although they continued to jump onto the ledge following the operation, they no longer called out. The sight of the window would determine the reflex of the jump, but the purpose was now lacking. Bianchi (1922) characterized his monkeys as having lost the ability to coordinate different elements of a complex activity.

Jacobsen (1935, 1936) found that bilateral frontal damage in monkeys caused impaired performance on both the delayed response and delayed alternation tasks. Since these animals performed normally under conditions of no delay, the deficit was interpreted as reflecting a loss of recent memory. Further series of experiments demonstrated that animals

had no difficulty on delayed response tasks if distractions were minimized and their attention fully captured (e.g., if lights were turned off during the delay period or if reward was obtained before as well as after the delay period (Finan, 1942; Malmo, 1942). As a result of these and other experiments, several explanations were offered to explain their behaviors: distractibility (Finan, 1942; Malmo, 1942); decreased drive (Pribram, 1960); and deficit in habituation (Kimble, Bagshaw & Pribram, 1965).

Pribram (1960) found that, after resection of the frontal lobes in monkeys, reinforcement of the motor reaction in a situation with complicated choices did not bring about required changes in the animal's behavior. He postulated a disturbance in the preliminary synthesis which regulates complex forms of behavior and in the evaluation of the effect of their own actions, without which goal-directed selective behavior is impossible.

In summary, while early animal experimentation shed light on many aspects of frontal lobe deficits, there was little consensus about underlying dysfunctions. Behavioral disintegration, decreased drive, problems with

habituation, short-term memory and distractibility were among the dysfunctions postulated.

A similar situation existed in the early clinical literature describing the results of frontal lobe pathology in man. While clinical observations provided a wealth of descriptive data, there was little consensus regarding underlying dysfunctions. Clinically, patients with frontal injury exhibited inability to organize their activities and approach new problems. Deficits were described in planning, particularly in the formulation of new plans and in the ability of those plans to control behavior (Ackerly & Benton, 1947; Brickner, 1934, 1936; Feuchtwanger, 1923; Harlow, 1868; Luria, 1966, 1969, 1973; Penfield & Evans, 1935). Difficulty in registering more than one impression at a time and decreased ability for mental synthesis were also described (Mettler, 1949).

While there was general agreement in the descriptive aspects of the "frontal lobe syndrome", authors varied in their opinion of underlying factors. Goldstein (1944), Halstead (1947), Rylander (1939), and others suggested that patients with frontal damage showed significant impairment of intellectual ability and that, the more complex and integrative the task,

the greater the dependence on the integrity of the frontal lobes. Each of them, however, differed with respect to the nature of the deficit involved. Goldstein believed the deficit was due to loss of abstract attitude; Rylander saw it as a basic deficit in reasoning; Halstead believed biological intelligence was affected. Brickner (1936) maintained that it resulted from a loss in the power of synthesis.

Other researchers have claimed that no real "intellectual" losses followed frontal injury but rather that cognitive deficits were indirect results of personality changes such as lack of motivation or loss of foresight and awareness of "self" by the self (Freeman & Watts, 1950). Others, such as Arnot (1952), viewed the observed deficits as evidence of frontal involvement in the persistence of emotional states, chains of thought, motor actions and inhibition. Robinson (1941) attributed the deficits to a decreased capacity for prolonged attention.

Finally, several investigators found no evidence of deficits. For example, the Columbia-Greystone study (Mettler, 1949) found no evidence of permanent intellectual impairment following ablations to prefrontal orbital areas. Results indicated no changes in learning, memory or the

formation of associations, no alterations in the ability to abstract and no loss of creative ability, imagination or high-level intellectual achievements. Hebb and Penfield (1940) and later Teuber (1964) also found little evidence of intellectual impairment after frontal extirpation.

This dismissive view of the intellectual functions of the frontal lobes was reinforced by subsequent research. Initial investigations using IQ measures showed that patients with frontal lesions performed at a level in no way inferior to patients with posterior lesions or, indeed, to non brain-damaged individuals (Hebb, 1945). Later research has borne out Hebb's observations that frontal lesions do not have a disproportionate effect on IQ test performance (Mettler, 1949; Milner, 1975; Smith, 1966).

At the time that Hebb made his observations, Goldstein (1944) counterclaimed that standard IQ tests do not allow higher level deficits to manifest themselves. Recent reviews support Goldstein's view (Shallice, 1988; Stuss & Benson, 1986). It is now generally believed that the "silent" role of the frontal lobes can be explained on the basis of the requirements of tasks used to assess their function.

Specific facts about the role of the anterior brain areas are accumulating. Frontal pathology, unless massive, does not affect intellectual functioning at the level of well-learned information and well-rehearsed abilities tapped by standard tests of intelligence. Furthermore, basic abilities in memory, visual-spatial functions and language, although having direct and reciprocal connections with the frontal cortex, can function independently of the frontal lobes with overlearned knowledge or in well-rehearsed situations (Stuss, 1986). A better understanding of the specific circumstances which activate the frontal lobes is crucial to uncovering their role in behaviour. Frontal lobe input is not required for rapid or routine behavior, even if the behavior is relatively complex. Thus, when tasks are based on stereotypes of previous experience, activity may remain unimpaired. Conversely, when tasks demand the creation of new programs of action and choices among several equally probable alternatives, activity may be disturbed (Luria, 1969). This is evident in frontal lobe patients who can, for example, respond to ordinary questions or perform habitual actions, but are unable to carry out complex, purposive, goal-directed actions (Luria, 1973).

The above review highlights the contradicting nature of the historical view of frontal lobe function. Several reasons can be postulated for the lack of agreement. One reason is that early investigators tended to regard the frontal lobes as a homogeneous mass. Different disorders, however, arise in patients with lesions of the right or left frontal lobes and with lesions of convexity or basal frontal regions (Luria, 1973). It is now becoming increasingly evident that the frontal lobes are both anatomically and functionally heterogeneous. As our knowledge in this area increases, more precise localization and more accurate assessment of frontal impairments is becoming possible.

A second reason is that early investigators were beset by a lack of formal definition of aspects of behavior and cognition being evaluated. Hypothetical constructs were very broadly defined and little or no breakdown of component processes of complex acts was attempted. As definition of terms became more precise and task demands more clearly outlined, it became evident that the underlying substrates of generic disorders such as deficits in abstraction, intelligence, synthesis and so on, reflected disorders of prefrontal function. Furthermore, frontal lesions appear to affect different types of intellectual operations unequally. Tasks

which are integrative and those that require new learning are more dependent on the input from the frontal lobes.

At present, advances in the theoretical study of cognitive processes, and greater specificity in our knowledge of anatomical subdivisions and functional heterogeneity, are leading to a growing solution to "the riddle of the frontal lobes". In order to gain some insight into the nature of this growing solution, a brief discussion of advances in these two areas follows.

Anatomical and Functional Evidence of Heterogeneity in Animals

The heterogeneity of the frontal lobes has been demonstrated by a number of anatomical and behavioral investigations. In work with patients, it has been difficult to establish critical regions other than in a gross manner within the frontal cortex because lesions are rarely confined to anatomically distinct regions. Work with nonhuman primates, on the other hand, can overcome this problem. As a result, much of the following data is based on work with non-human primates.

According to Goldman-Rakic (1984) one key to understanding the functions mediated by the frontal lobes is detailed knowledge of the connections which link them to major sensory centers and to subcortical centers. Traditionally, the frontal lobes have been divided into three principal regions: precentral, premotor and prefrontal. The precentral region is the classic motor cortex; stimulation of this area results in phasic body movements (Wise & Evarts, 1981). The area lying just in front of the motor cortex is the premotor region and contains several functional areas including the supplementary motor area, frontal eyefields and Broca's area. The remainder of the frontal lobes comprises the prefrontal region (Pandya & Barnes, 1987). It is this prefrontal region which will be the focus of the present study.

The prefrontal cortex, which includes Brodmann areas 8-12, constitutes frontal association cortex. Extensive cortico-cortical connections radiate outward to the prefrontal cortex from the three major sensory centres of the parietal, temporal and occipital lobes. Efferent fibers travel to the anterior temporal cortex, inferior parietal lobule, cingulate and parahippocampal gyri (Nauta, 1971, 1973).

As more anatomical knowledge is gathered, the important conclusion is that the prefrontal cortex is organized into separate territories defined by higher order inputs originating in the primary sensory cortices and can be considered anatomically and functionally heterogeneous (Goldman, 1979). For example, Goldman and Nauta (1976) demonstrated a prominent connection from the middle third region of the principal sulcus to intermediate and deep strata of the superior colliculus. This pathway, along with a similar pathway from the frontal eyefields, shows that a considerable portion of the dorsolateral convexity projects to the superior colliculus. Since the superior colliculus is important for localizing and tracking targets in space, the prefrontotectal connection may explain the loss of spatial abilities (e.g., impaired performance on forms of delayed response tests where correct spatial orientation is crucial) in monkeys with cortical principal sulcus lesions. In contrast, Goldman and Rosvold (1970) showed that lesions to the arcuate sulcus affect performance on spatial tasks without delay, suggesting at least two functionally distinct subdivisions of dorsolateral prefrontal cortex.

Anatomical studies have also revealed major, previously unrecognized, connections between the prefrontal cortex and posterior

parahippocampal and presubicular cortices that may be part of the circuitry used for spatial short-term memory (Goldman-Rakic, Selemon & Schwartz, 1984); between prefrontal cortex and neostriatum, which may form part of a functionally coupled neural system for regulating voluntary motor behavior (Goldman-Rakic, 1984); and regions of the prefrontal cortex that possess larger or smaller visual receptive fields concerned with central and peripheral visual processes (Suzuki & Azuma, 1983).

In general, animal literature suggests that there are at least two functional systems: a dorsolateral system and an orbitoventral system. Rosvold (1972) has demonstrated subcortical counterparts that fit with each of the major anatomical-functional frontal lobe systems. Pandya and Barnes (1987) proposed that, by virtue of interconnections among evolutionarily related regions in a given stage, units were formed that subserve individual functions. They postulated that one portion of the frontal lobes developed from the rudimentary hippocampal formation and differentiates through the cingulate gyrus. This dorsal trend would be responsible for the cortex of the medial surface of the frontal lobe and the dorsolateral surface of the prefrontal cortex down to the level of the principal sulcus as well as the dorsal premotor and precentral regions. The other portion originates in or

near the olfactory cortex, differentiates through the insular proisocortex and gives rise to the cortex of the orbital surface of the frontal lobe and ventrolateral surface up to the level of the principal sulcus as well as the ventral premotor and precentral regions.

According to these authors, the dorsal system appears to be involved in the spatial analysis of sensory information, while the ventral system is preferentially concerned with the emotional tone of sensory information. The sequential processing of spatially related and motivational information in the dorsal trend and the object related information as well as the emotional types of information conveyed by the ventral trend, interact in the frontal lobes. This integrated information is then relayed via premotor regions to the precentral gyrus to initiate proper motor responses. These two systems evolved separately and process information separately. Nonetheless, they are anatomically interconnected and, in functional terms, must interact to produce the execution of smooth, integrated behavior which is the outcome of frontal lobe activity (Pandya & Barnes, 1987).

Evidence of functional heterogeneity has also been accumulated by other methodological procedures. Blood flow studies recording brain

activity during both complex and simple motor and intellectual tasks have provided data regarding functional heterogeneity of the frontal lobes. For example, Roland (1984) identified seventeen functionally distinct areas of the frontal cortex based on patterns of activation during a wide variety of mental or motor processes in normal human subjects. Fuster, Bauer and Jervey (1982) recorded single unit activity in dorsolateral prefrontal cortex of monkeys during two visual short-term memory tasks. Their findings suggested the coexistence, in prefrontal cortex, of cells that change activity in correlation with each of the temporally separate events in the sequence that constitute a delay-task trial, with each event affecting different cells in close proximity of each other. Rosenkilde, Bauer and Fuster (1981) reported similar findings in ventral prefrontal cortex of monkeys.

The heterogeneity indicated by the anatomical research is mirrored in behavioral studies. Petrides (1982, 1985a, 1985b, 1986, 1987) examined the role of periarcuate cortex in conditional learning. In conditional situations, monkeys are faced with a set of stimuli and a set of arbitrary responses and have to learn to perform according to the conditional rule: If Stimulus A is presented, select Response X; if Stimulus B is presented, select Response Y. Petrides (1982) administered such a task to monkeys

with periarcuate lesions. In the control task, animals were rewarded for a response to the 'positive' but not to the 'negative' stimulus. Petrides found that none of the animals with periarcuate lesions was able to reach criterion within the limits of testing on the conditional learning task. In contrast, these animals performed as well as normal controls if they were not required to select between alternative responses but simply had to perform a single response in the presence of a stimulus leading to a reward. The normal performance of these animals on this control task, as well as on various nonconditional tasks, rules out the possibility that deficits are due to difficulties in discriminating between the visual stimuli used or to impairments in motivation or attention.

Further evidence of the involvement of the periarcuate cortex in conditional learning was provided by subsequent studies investigating the performance of symmetrically and asymmetrically reinforced go/no-go tasks (Petrides, 1986) and different nonspatial conditional tasks (Petrides, 1985a). In the symmetrically reinforced tasks, the animal had to learn to respond immediately, if Stimulus A was presented (go). If Stimulus B was shown, they had to learn to wait until the end of delay period to respond (no-go). The requirements of this task were therefore similar to those of a

conditional task. Results indicated that monkeys with periarcuate lesions exhibited significant impairments on such tasks; in contrast, they performed as well as normal control subjects on asymmetrically reinforced go/no-go tasks in which they were rewarded if they responded in the presence of positive stimuli, but were never rewarded if they responded in the presence of negative stimuli.

In the non-spatial conditional task (Petrides, 1985a), one of two boxes, placed close to each other, was lit while the other remained unlit. The monkeys were rewarded if they opened the lit box when Object A was shown and if they opened the unlit box when Object B was presented. Animals with periarcuate lesions were severely impaired in learning this nonspatial conditional task.

The work carried out by Petrides shows that damage to the periarcuate cortex results in severe impairments in various conditional tasks. Furthermore, selective lesioning of this region revealed that some degree of separation, in terms of mechanisms underlying different conditional tasks, exists in this region (Petrides, 1985b). Damage to the anterior part of the periarcuate cortex, which is connected with the visual

system resulted in severe impairment on conditional tasks in which the appropriate response could only be determined on the basis of visual characteristics (a lit or unlit box). By contrast, damage to the posterior part of the periarcuate cortex, linked closely to the motor cortex and the somatosensory system, caused a severe impairment in the post-operative acquisition of a conditional task which required selection between two kinesthetically distinct responses, i.e. responses which can be differentiated on the basis of differences in the motor program needed to activate them. These data suggest a separation within prefrontal cortex of mechanisms which subserve conditional learning in terms of the sensory modality through which a stimulus is presented, and the types of responses which must be produced.

Fuster (1980, 1984, 1985), by analysis of lesion effects, neuroelectrical phenomena and metabolic activity, concluded that different topographic representation exists within the frontal lobes for at least three cognitive functions: short-term memory, preparatory set and control of interference. According to Fuster, the memory function and preparation set are predominantly disturbed by lesions of the cortex of the dorsolateral

prefrontal convexity; interference control is impaired following lesions of inferior or orbital prefrontal cortex.

In sum, both anatomical and behavioral research in animals indicates heterogeneity in structure and function within the frontal lobes.

Localization of Function in Man

Localization of function within the frontal lobes of man has been difficult. Most research suggests a relation of size of lesion and deficit; the larger the lesion, the greater the degree of impairment (Luria, 1969, 1973; Warren, 1964). While factors such as etiology, duration since damage, sex differences and test employed obscure results, certain findings appear to be consistent.

One localization differentiation is based on a rostral-caudal direction with greater deterioration the more caudal the pathology (Hamlin, 1970; LeBeau, 1952, 1954; Petrie, 1952; Smith, 1960, 1964). Another is based on the dorsal-lateral, orbital and medial cortical surfaces. Assessment of executive functions has revealed greater losses on the

Porteus Maze test after superior forebrain ablation than after orbital topectomy (Porteus & Diamond, 1962; Smith, 1960, Smith & Kinder, 1959). Deficits in the performance of the Wisconsin Card Sorting Test appear to be maximal after dorsal-lateral lesions (Milner, 1963, 1964, 1971). Other differences based on this differentiation have been found in mood (Baker, Young, Gauld & Fleming, 1970), verbal fluency (Milner, 1963, 1964), verbal regulation of behavior (Luria, 1960, 1966, 1969) and motor functions (Blumer & Benson, 1975; Kleist, 1934; Lishman, 1968).

Differences in behavioral changes have also been found based on laterality of pathology. These differences generally reflect the visual-spatial/verbal differences of the two hemispheres (Stuss & Benson, 1983). For example, impaired verbal fluency occurs after either left or right frontal pathology (Benton, 1968; Ramier & Hecaen, 1970) but is more severe with left frontal involvement (Hecaen & Ruel, 1981; Milner, 1964; Perret, 1974). Deficits in design fluency on the other hand are greater in patients with right frontal or frontal-central pathology (Jones-Gotman & Milner, 1977). Visual-perceptual and visual-constructional abilities, if impaired at all after frontal damage, are

greater with right frontal damage (Benson & Barton, 1970; Black & Strub, 1976; Milner, 1971; Taylor, 1979).

Memory recency tests have also revealed left versus right differences. Left frontal patients were most impaired on verbal recency tests only, while right frontal patients were impaired on both verbal and non-verbal tests. These tasks required the temporal ordering of two recent events and therefore involved monitoring an externally ordered sequence. As a result it was suggested that the right frontal lobes are dominant for visually guided attention required to monitor sequences of externally-ordered events (Milner, 1982; Petrides & Milner, 1982). Using verbal and non-verbal subject-ordered tasks, Milner (1982) found that patients with left frontal pathology were impaired on both tasks while the right frontal group showed deficits on non-verbal tasks only. These results were interpreted as evidence of dominance of the left frontal lobes for programming of voluntary actions, required by subject-ordered tasks.

Although not as specific as the localization in animals (Rosvold, 1972), these examples suggest that there are differences in behavioral changes in humans depending on size and location of lesion. Furthermore,

a growing body of evidence suggests that functional systems may also exist in man. For example, Alexander, Stuss and Benson (in press) postulated four frontal systems for language, based on evidence of specific speech, language and communication deficits following lesions to different regions of the left or right frontal lobe. The first system is 'motoric' and comprises lateral and posterior regions of the frontal lobes and the subcortical efferent pathways of those regions. Left hemisphere lesions in this system produce articulation impairments; right hemisphere lesions impair affective prosody. The second system is 'cognitive' and is comprised of the middle lateral convexity. Left hemisphere lesions here result in poor word finding and grammatic usage, as well as problems in piecing together fluid sequences of words. Right hemisphere lesions in this system result in pragmatic and affective communication impairments.

The prefrontal region comprises the third 'paralinguistic' system. Left-sided lesions in this area would affect the organization and manipulation of language; right sided lesions impair organization and response to the social and situational context of the communication. The fourth and final 'activation' system includes the posterior medial frontal lobes including the supplementary motor area and anterior cingulum. Left

hemisphere lesions produce mutism; right hemisphere damage produces similar though less severe deficits. In summary, based on clinical-anatomical correlations for language, these authors have postulated the existance of several separate functional systems, anatomically organized in the human brain.

The data reviewed suggests that the frontal lobes and, more specifically, prefrontal cortex can be considered anatomically and functionally heterogeneous. These findings begin to account for some of the inconsistencies in the early literature. Evidence suggests that different sectors of the prefrontal cortex serve different behavioral functions. Many functions, however, can be viewed as components of a superordinate function serving a wide range of cognitive and motor activities. As a result, while deficits after frontal lobe damage can be attributed to problems in a broad, underlying supervisory or 'executive' function, different frontal lesions may interfere with different component processes of this function and thus lead to qualitatively different deficits.

Advances in cognitive psychology parallel the anatomical and functional developments outlined above. As more knowledge is gathered,

the tendency has been to abandon unitary concepts when considering complex mental processes. As a result, a trend toward component theories has evolved. These theories attempt to break down complex functions into component processes. Theoretical input from the area of cognitive psychology has now begun to be integrated with theories of frontal lobe function. A review of pertinent advances follows.

Cognitive Science and the Frontal Lobes

Until recently input from cognitive psychology has been limited because cognitive theories have often contained a single selection unit or general executive component (e.g., Shiffrin & Schneider, 1977). Many now consider single component models insufficiently powerful to explain high-level cognitive disorders (Shallice, 1982). More complex models are being developed (Newell & Simon, 1972; Shallice, 1982; Sussman, 1975).

One example of an attempt to link neuropsychological issues to information processing concepts comes from the work of Shallice (1982, 1988) and Norman and Shallice (1986). While it is only one of many models which exist today, the Norman and Shallice model merits closer

investigation within the context of this study in that it incorporates issues of functional heterogeneity, clinical observations and frontal lobe function within a cognitive framework.

Norman and Shallice's model developed from an attempt to anchor Luria's overall theory of frontal function within a conceptual framework of cognitive science. According to Shallice (1988), while Luria's theory of a system for programming, regulating and verifying activity is closest to ideas in cognitive science, it falls short in that a concept such as 'programming' can be applied to describe different levels of the control of action and thought. For instance, when one carries out an action like lighting a cigarette or cutting a slice of bread one can be said to program the outflow to effector mechanisms. This, however, does not appear to describe the level of programming impaired in frontal patients (Shallice, 1988). As a result, clear qualitiative distinctions must be drawn between the different levels.

Norman and Shallice's (1986) model thus consists of a two-part system; the first component, called "contention scheduling", ensures in a routine way the efficient use of limited effector and cognitive resources and

is sufficient for relatively simple or well learned acts. This component selects schemas (units which control over-learned actions or skills) on the basis of strength of activating environmental triggers (for example, a red traffic light will automaticaly trigger schemas controlling actions necessary to bring a car to a halt).

This process of routine selection between routine actions or thoughts (contention scheduling) does not provide a sufficient basis to explain all levels of the selection of thought and action operations (Shallice, 1988). In artificial intelligence it has been found necessary to add a planning component to problem solving. This component operates differently from a system which executes solutions routinely; it learns from its mistakes, and does not sacrifice flexibility for speed of operation. Norman and Shallice's model incorporates such a planning unit. When non-routine problems require solution, the second component of the model, the Supervisory Attentional System (later redefined as the Supervisory System - SS (Shallice, 1988)) is activated. This system allows for conscious, attentional control to modulate performance. The SS is a general planning component containing schemas that can be applied in any domain; these schemas are necessary in setting out procedures for solution

of complex or novel problems where the order of action schemas must be created. Thus, the SS comes into play when contention scheduling fails or when no routine solution exists. Selection of schemas through this component now becomes slow and flexible rather than fast, routine and unchanging. The SS achieves its function of guiding non-routine solutions by modulating the lower level contention scheduling system through additional activation of appropriate general planning schemas or inhibition of inappropriate schemas. It does not directly select schemas.

A routine task does not require continuous monitoring and activation of the SS; contention scheduling alone is sufficient to select the appropriate component schemas. Selection of schemas takes place on the basis of activation value alone. In contention scheduling, a schema is selected whenever its activation exceeds a particular threshold specific to that schema.

The necessity of an additional system involved in non-routine selection is supported by examples of "action lapses" or failures in normal selection of actions. Occasionally an incorrect schema can become strongly activated in contention scheduling and capture the effector systems. For

example, Reason (1979) describes how one of his subjects, when passing through his back porch on the way to getting his car, stopped to put on his gardening jacket and boots as if to work in the garden. These 'capture errors' result if the SS is being directed elsewhere or if its function is impaired. If the SS is inoperative, the organism will operate under the control of contention scheduling alone. If the environmental situation is such that a trigger is present which strongly activates a schema, it will not be possible to prevent that schema from being selected.

Shallice cites examples from the work of Lhermitte (1983), of a tendency in some frontal patients for action to be triggered inappropriately by stimuli. Lhermitte clinically described 'utilization behavior' in 5 patients with localized frontal lesions. In his procedure, an object such as a glass is brought within reach of the patient. The patient grasps it. A bottle of water is then placed on the desk. The patient grasps this object too and then pours water into the glass and drinks it. Analogous behavior was found with other objects. According to Shallice (1988), utilization behavior fits well with how contention scheduling operates when it is not subject to Supervisory System control.

Clinical descriptions of behavior after frontal lobe pathology reveal several examples of how actions may be triggered inappropriately by stimuli. For example, frontal patients can perform imitative acts without difficulty (e.g., reproducing corresponding movements made by an examiner). If, however, the patient is given a spoken command which clashes with what is directly perceived (e.g., raise your hand when I raise my finger; I tap once, you tap twice and vice versa), he will have difficulty in carrying out the instructions; after a short time, responses will be replaced by repetition of the directly perceived signal (Luria, 1973).

Other examples are again found in Luria's (1973) description of performance on thematic pictures following frontal pathology. Normally, in analyzing thematic pictures for meaning, the solver must distinguish the details, compare them and formulate a hypothesis of the meaning and finally test this hypothesis against the content of the picture. Frontal patients grab one particular detail and put forward suggestions on the meaning of the whole through routine associations with the fragments they have perceived.

The above clinical examples show how susceptible frontal patients may be to strong stimuli in the environment. These stimuli, and the automatic associations linked to them, may disrupt the execution of multi-step, serial programs of action. Norman and Shallice's model attempts to understand the input of the frontal lobes, represented in the functioning of the SS, in such behavior. First, it isolates one of the procedures which may be performed by the frontal lobes. This procedure involves biasing or overriding the selection of routine reactions or associations to strong environmental triggers, and activating in their place "general planning" schemas. These general planning schemas direct well-learned skills in novel ways in order to achieve accurate solutions. The conditions which necessitate its input are those in which a routine solution is inadequate or where solutions were not previously learned. This includes tasks which fit within the following categories:

1. They involve planning or decision making.
2. They involve components of trouble shooting.
3. They are ill-learned or contain novel sequences of actions.
4. They are judged to be dangerous or technically difficult.

5. They require the overcoming of a strong, habitual response or resisting temptation.

(Norman & Shallice, 1986)

Finally, the model suggests that, without the appropriate monitoring and activation by such a supervisory system, strong environmental triggers could activate automatic associations, lead to capture errors and disrupt the execution of multi-step, serial programs of action.

The Supervisory System corresponds to Luria's system for the programming, regulation and verification of activity postulated to involve the frontal lobes (Shallice, 1988). Its primary function is that of producing a response to novelty that is planned rather than one that is routine or impulsive. The situations in which it is required are those where the routine triggering by the environment of the individuals's specialized thought or action schema is insufficient to produce an appropriate response. Instead, some form of problem solving behavior, trying out hypotheses, and learning from failed attempts is required. Shallice further postulates that the SS is complex in its internal structure, i.e., does not perform one function but is composed of different processes.

Shallice's model provides one framework within cognitive psychology in which the elusive function of the frontal lobes may be interpreted and provides a close parallel to clinical and experimental observations. Shallice suggests that the frontal lobes perform a superordinate function, made up of several components, which is required only under very specific conditions i.e., when tasks are novel or complex. Different components may be activated, based on the requirements of the task.

In summary, three separate sources have led to a multicomponent view of the prefrontal cortex, replacing the concept of a global frontal-lobe syndrome. First, neuropsychological evidence has increasingly shown that deficits in several functions (memory, cognition, etc.) are not due to actual losses of those functions per se, but in the control or use of those functions, depending upon task requirements which demand frontal input. Second, anatomical and animal behavioral evidence has clearly documented the anatomical and functional heterogeneity of the frontal lobes. Finally, cognitive psychology has proposed more fractionated models of cognition to replace single component theories. In such models, components are viewed as separate processes of a superordinate function.

The Growing Solution in Neuropsychological Investigations

Researchers generally agree that the frontal lobes are involved in a directive, organizational, controlling role of more specific functions such as memory, language, attention and so on. According to Stuss and Benson (1987) the frontal lobes play a controlling role in relation to the rest of the brain and are pressed into action only when such control is demanded. Specific component processes of such a superordinate function, however, remain to be clearly identified. Furthermore, the conditions which require frontal input in behavior are still not well defined. The growing solution in neuropsychological investigations of frontal lobe function requires study of separate processes in relation to task demands.

As more and more interest is focused on the directive, organizational functions of the frontal lobes, some attention has been turned to the issue of sequencing, since it is an integral part of the ability to plan and organize behavior. The present study will attempt to examine the relationship between frontal lobe function and sequencing ability within the framework outlined above. Such a framework emphasizes the existance

of various unique processes which the frontal lobes bring to bear on behavior, in response to very specific demands of a task.

The Frontal Lobes and Sequencing

While there is general consensus in the literature that frontal pathology disrupts sequential behavior, opinions have differed with regard to the nature and severity of underlying dysfunction. One reason for such confusion is the lack of definition regarding what level of sequencing was being examined.

Definition of sequencing is required since sequencing can be defined in at least two different ways. First, it can be defined as a range of simple to complex serial tasks which are automatic and overlearned. This type of task would not be considered to involve the frontal lobes. Second, it can be defined as the ability to carry out logical sequences of responses in situations which require creative non-automatic solutions, where goals are not directly attainable. Here, solutions require a set of coordinated actions with several intervening steps including the possibility of dead ends and

false starts. In such circumstances, sequencing may be regarded as involving the frontal lobes.

A review of studies examining the relationship between sequencing ability and the frontal lobes is presented here. While these studies reflect the problem of definition discussed above, some valuable patterns can be observed from the existing data.

Frontal deficits have been described on a wide range of sequential tasks, from psychometric tests such as the Picture Arrangement subtest of the WAIS-R (McFie & Thomson, 1972; Stuss et al., 1983) to tasks demanding serial organization (Brody & Pribram, 1978; Kaplan, Fein, Morris & Delis, in press; Luria, Pribram & Homskaya, 1964; Milner, 1982; Petrides & Milner, 1982; Pribram & Tubbs, 1967), to multistep behavioral acts, solution of complex problems and goal-directed behavior in general (Luria, 1973; Pribram, 1973; Shallice, 1982; Shallice & Evans, 1978).

Luria (1973) postulated that programs consisting of a sequence of consecutive actions presents the brain with a series of complex demands: the subject has to first retain the verbal or visual instruction given to him;

he must grasp the necessary scheme of the action and analyze its subsequent action into a series of successive subprograms; he must constantly check each component of the action as he performs it against the original program and correct mistakes which may arise in the course of its performance. Finally, aftereffects of each particular act must be inhibited as they arise and, at the proper time, there must be a switch to the next component of the action.

According to Luria (1966, 1973) when tasks requiring a series of consecutive actions are presented to patients with frontal lesions, the programs of action are quickly disturbed by perseverations of individual elements or are substituted by simplified programs. For instance, if a patient is asked to tap a rhythm consisting of one strong and two weak beats (/") this asymmetrical program may soon give way to a symmetrical one (e.g., two similar beats // // //) or disintegrate as the patient increases the number of taps. Patients also have difficulty with performance of an assigned program if conditions of the task require them to switch from one program to another. For example, when a patient is instructed to draw a series of figures consisting of alternating asymmetrical components (e.g., two crosses, 1 circle), the program is easily

oversimplified, with the patient repeating only one component, or one cross, one circle, etc.

All of the above relate to problems in following externally provided sequential programs. Luria further suggests that deficits are as marked when patients have to find their own essential program and subordinate future actions to that program. Usually in such a case, a subject analyzes a situation and distinguishes those components most likely to lead to a solution; these methods of solution determine subsequent action. Actions corresponding to these hypotheses arise with the greatest probability; those not corresponding are inhibited (Newell, Shaw & Simon, 1958). In examining the performance of frontal patients on the formation of search programs (i.e., touching a group of tokens forming letters, with eyes closed; discovering under which of 12 squares an object is hidden), Luria (1966) reports that necessary action programs are not formed but rather that patients continue to search for the object by random movements, or subordinate their movements to irrelevant factors.

Milner (1982), and Petrides and Milner (1982) recently provided further evidence that frontal deficits occur in tasks requiring serial ordering

both when tasks involve sequences established or required by the external environment (such as monitoring externally ordered sequences in a Recency Discrimination Task) and when internal organization must be supplied to sequential acts (as in a Subject-Ordered Pointing Task).

On the Recency Discrimination Task the subject was a passive observer of the order in which stimuli were presented. This task involved a pack of cards on each of which two different stimuli were presented. From time to time, a card appeared bearing two stimuli with a question mark between them. The subject had to say which of the two stimuli he saw most recently. While Petrides & Milner (1982) found evidence of strong material-specific effects related to the side of frontal-lobe lesion, their results also suggested a greater overall contribution from the right frontal lobe to the performance of such tasks.

In contrast, the Subject-Ordered Pointing Task required the subject to organize and carry out a sequence of responses. This task included a series of cards on which the same set of stimuli was presented. The position of the stimuli varied randomly from card to card. The subject was required to go through the cards, pointing to one stimulus per card, without pointing to

any item more than once. This task required monitoring of responses made in relation to those that still remained to be carried out. Frontal deficits could thus be related to poor organizational strategies or poor monitoring of responses, or both. Petrides and Milner (1982) found greater deficits in left frontal patients on this task, regardless of verbal or non-verbal factors.

These authors argued that the findings were consistent, in a general sense, with the suggestion that the left hemisphere plays a dominant role in the programming of responses. More specifically they suggested that rather than representing a loss in the ability to sequence per se, these deficits could be considered secondary to a loss in higher-order control and organization of procedures required to carry out sequential tasks. While the ability to perform individual actions that make up the sequence was preserved, serial organization was lost, with the result that some actions were performed in the wrong order or omitted altogether.

Brody and Pribram (1978) trained normal monkeys and monkeys with resection of anterior frontal or posterior parietal cortex to perform two sets of sequencing problems. These demanded that monkeys internally organize sequences on each trial rather than providing them with a predetermined

externally imposed set of rules to guide their responses. The frontal group demonstrated a significant impairment in learning sequences, but only when the monkeys were naive. Once they became sophisticated, they learned each sequence at a normal rate. According to the authors, the results indicate that sequencing per se is not dependent on intact functioning of the frontal lobes. They suggested, rather, that the frontal cortex is involved in higher-order control which is needed to allow the organism to pick out relevant details in a complex situation and to allow flexibility of response in tasks where demands are variable and changing.

Shallice (1982) tested general planning ability in patients with anterior or posterior lesions. The task was a modified version of the Tower of Hanoi, a look-ahead puzzle which required constructing a stack of blocks from a starting configuration through a series of individual moves. Successful completion of the task required the appropriate ordering of individual moves and the decomposition of the task into subgoals. If the subgoals were tackled in the wrong order, or if any subgoal was omitted, the puzzle could not be solved. Results showed a marked left anterior deficit on the task, but only as the number of moves required for solution increased. These results indicated that, while basic sequencing ability is

retained, factors which increase complexity (e.g., length) can disrupt performance of frontal patients on such tasks.

In sum, deficits on a wide range of sequential tasks are seen after frontal damage. These deficits are noted both on tasks where sequences are externally provided and in instances where sequences must be independently established. Furthermore, it appears that only specific types of sequencing tasks, requiring greater organization and directive input, fall under the domain of the frontal lobes.

Purpose of the Study

The aim of this experimental study was to examine some characteristics of sequential tasks which rely on intervention by the frontal lobes. This was done by manipulating two conditions within a sequencing paradigm. These conditions were chosen because they appear to create demands which necessitate frontal lobe input.

The first manipulation involved length of sequences. Input of the frontal lobes is presumably required only as tasks grow more complex or when no previously learned solutions exist. Complexity may refer to amount of information to be processed within a task, to simultaneous demands to be handled at once, to time and speed considerations and so on. Increasing length of sequencing tasks appears to increase complexity (Milner, 1982; Shallice, 1982). Performance of frontal patients was assessed at four levels of increasing complexity (defined as increasing length of sequence). Two of these levels are well within normal span (4 and 6 units); the third and fourth are at the upper limit of normal span or exceed it (9 and 12 units). If increasing complexity requires frontal input, we would expect no frontal deficits on serial tasks requiring the organization of sequences which are well within normal span length, regardless of modality of presentation, while deficits may be expected on sequencing tasks when the number of elements within a sequence exceeds normal span length.

The second manipulation in the present study involves conditions which require overriding the selection of routine responses within a sequencing paradigm. Clinical examples suggest that patients with frontal

lobe damage are vulnerable to strong environmental stimuli and may react to these in characteristic ways, even though such a reaction is improper within a particular context (e.g., utilization behavior (Lhermitte, 1983).

Norman (1981), Norman and Shallice (1986), and Shallice (1982, 1988) have described action slips or 'capture errors' in action sequences where a schema for an incorrect action is more strongly activated than a correct schema and thus captures effector mechanisms.

In individuals with no brain injury, such action slips are associated with being distracted or preoccupied. In such cases, no activation is presumably being received from the system responsible for monitoring on-going behaviors, the SS. Norman and Shallice (1986) link the SS to the integrity of the frontal lobes. Thus, these authors attribute clinical descriptions of similar derangements of on-going serial acts after frontal damage to inadequate control from frontal systems. On the basis of the above, it can be postulated that certain tasks require the input of the frontal lobes to override selection of familiar, routine associations when these are inappropriate within the general context of the task. Accurate solution of the serial task in this case requires breaking the routine

association and using the items in a non-routine way. On the other hand, tasks which contain routine associations which must not be overridden would not necessitate the input of the frontal lobes.

In the present study, specific sequences were devised which incorporated these two conditions. Each sequence contained two units which are frequently associated. Pictures of actions which usually follow one another (e.g., alarm clock rings, alarm is shut off) or two words frequently used as a pair (e.g., red roses, first aid) were presented. The validity of the association between the units was manipulated. In some cases the association was valid (i.e., correct organization of the sequence required that these two units be used in the presented routine way). In other cases, the association was invalid (i.e., correct organization of the sequence required that the two units be separated and used in a different way).

If a specific system is responsible for monitoring on-going behaviors and intervening in non-routine solutions and if such a system is not operational, or if its function is impaired, deficits would be found on such a task. If this control function is specific to the frontal lobes, we would

expect only patients with frontal lesions to experience difficulty with this task, provided that there are no confounding problems such as a severe comprehension disorder.

A secondary aim of this study was to examine hemispheric differences on sequencing tasks. Of particular interest were differences which might occur between left and right anterior patients, given existing evidence of such differences on other sequencing tasks reported in the literature (Petrides & Milner, 1982; Shallice, 1982). For this purpose, verbal and pictorial counterparts of the sequencing tasks were devised.

Summary of Hypotheses

Hypotheses are presented in the direction of expected results. Hypotheses are formulated only for definitive group comparisons.

1. The performance of patients with frontal lesions will be significantly lower than that of both their normal control group and a posterior brain-damaged group on tests requiring the organization of sequences,

when the length of the sequence exceeds normal span, regardless of modality.

2. The performance of patients with frontal lesions will be significantly lower than that of both their normal control group and a posterior brain-damaged group on sequencing tasks in which conditions that may lead to capture errors are present.

METHOD

Subjects

Two main groups of subjects were investigated. The first, Patient Group, comprised of brain-damaged patients with focal lesions from the Ottawa General Hospital, the Civic Hospital and the Baycrest Centre in Toronto. The second, Control Group, consisted of subjects with no neurological history who volunteered their participation. In the Patient Group, 18 individuals with appropriate lesions, resulting from stroke or from surgery for tumors or clipping of aneurysms, were referred by physicians in the Neurology Service at the Ottawa General Hospital. At the Civic Hospital, 3 participants were obtained through a stroke study undertaken by Dr. J. D'Alton. Dr. M. Freedman referred 1 patient from the Baycrest Centre. The protocol had been approved by Ottawa General Hospital/University of Ottawa ethics committee. Subjects were fully informed and signed consent was obtained.

General Criteria

General criteria for inclusion in the study for all subjects included:

a) absence of history of hospitalization for psychiatric disorders;

b) absence of a history of neurological disease other than that being investigated (no neurological disorder for the Control group);

c) age between 18 and 70;

d) fluency in English.

In addition, all participants in the study were administered the Peabody Picture Vocabulary Test (PPVT) (Dunn, 1959), as an estimate of intellectual ability. Subjects were originally required to achieve a minimum percentile score of 50, reflecting an I.Q. score of 100. During subsequent subject selection, however, it was decided to include three subjects in the Patient Group who fell 1 standard deviation below an I.Q. score of 100, due to a lack of patient availability. Thus, anyone with an I.Q. score of 85 and above, within the average range or above, was included in the study.

While the PPVT was attempted with all subjects, two patients, one from each the Anterior and Posterior group, did not complete the test because test results were judged to be invalid measures of actual IQ. Administration of the test was discontinued for patient KR, of the Anterior Group because it was felt that performance on the PPVT was being confounded by residual word finding difficulties exhibited by the patient. Results of patient KA of the Posterior Group, were also considered to be an invalid estimate of IQ because this patient, while fluent in English, was originally educated in Turkey and was not familiar with some of the vocabulary included in the PPVT. On the basis of his very competent command of English (he is an engineer with a high level government position) and his subsequent high performance on the verbal subtests of the experimental tasks, he was included in the final sample.

Specific Criteria for Patients

Individuals in the Patient Group were required to meet a number of additional criteria before being included in the study to ensure that they met a minimum standard on functions considered relevant to perform the experimental tasks. As a result, patients were administered a series of

neuropsychological tests assessing functions such as mental control, comprehension and immediate visual memory. Control subjects were not administered these tests, as they measure only very minimal baselines of performance and present no difficulty in the absence of brain injury.

Attention

To ascertain that subjects possessed the basic ability to hold a normal span of information and could exercise adequate mental control in focusing and maintaining performance throughout the task at hand, the following tests were administered:

- Digit Span Forward [Wechsler Adult Intelligence Scale-Revised (WAIS-R)] (Wechsler, 1981). Subjects were administered all sequences (2 trials per sequence) up to and including a span of six numbers. Criteria for inclusion was set at a minimum of 1 correct sequence of 5 digits.

- Counting forward by 3's, counting backwards from 20-1 [Wechsler Memory Scale (WMS)] (Wechsler, 1945). Subjects were required to perform these tasks with a maximum of 1 error per task. If more than 1

error occurred, subjects were given a second trial. If the second trial was performed with a maximum of 1 error, the subject was considered to have passed this criterion. No time limit was established.

Comprehension

To ensure that subjects were able to understand the instructions of the experimental task, could recognize integrated pictorial representations and were able to read and understand verbal material, the following tests were administered:

- Modified Token Test (De Renzi & Faglioni, 1978). Subjects were required to achieve a minimum score of 15 out of a possible 16 on this test.

- Word-Picture Matching and Word Recognition subtests of the Boston Diagnostic Aphasia Exam (BDAE) (Goodglass & Kaplan, 1972). Subjects were required to complete both of these tests with a maximum of 1 error per test.

Memory

To ascertain that subjects were able to retain information administered in the visual modality the following was administered:

- A multiple choice version of the Visual Reproductions subtest of the WMS (Milberg, Hebben & Kaplan, 1986; Wechsler, 1945). Subjects were required to correctly identify a minimum of 3 out of 4 drawings on a multiple choice test for immediate as well as delayed recall after 20 minutes.

Neurological Criteria

Individuals in the Patient Group were also required to meet a number of neurological criteria before being included in the study. These criteria were established to control, as much as possible, for parameters such as locus, extent, etiology and chronicity of brain damage, thus increasing the validity of results obtained.

To ensure that subjects in the Patient Group met the neurological criteria, a neurological report was obtained for each patient (see Appendix 1) by Dr. J. D'Alton at the Civic Hospital, Dr. M. Freedman at Baycrest Centre and Dr. J. Willmer at the Ottawa General Hospital. The report included neurological history and assessment based on medical records or actual examination of the patients. CAT scans obtained at least 6 months post-injury were also examined and a detailed report of lesion parameters obtained (see Appendix 2 & 3).

Lesions were examined and classified on the basis of size, extent and quadrant occupied. Subjects were grouped by lesion site into two groups (Anterior (N=13), and Posterior (N=9)) on the basis of CAT scan analyses. For the purpose of this study, the brain was divided into halves with the Fissure of Rolando designated as the anterior-posterior line of demarcation. This schema is consistent with that used in similar research (Benson & Barton, 1970; Black & Strub, 1976). A minimum of 75% of pathology to either anterior or posterior brain regions was essential for placement into one of the two groups.

Further subdivision of patients within the Anterior and Posterior Groups was carried out for descriptive analyses. Patients were classified into four groups based on specific quadrant of lesion location. A minimum of 75% of pathology to one quadrant (Right Anterior, Left Anterior, Right Posterior, Left Posterior) was essential for placement in one of the four groups. While it is difficult to establish with certainty whether the contralateral hemisphere is completely free from lesions, the possibility of damage other than in the primary quadrant was minimized by neurological and neuroradiological procedures. Two patients assigned to the Anterior Group were not included in quadrant analyses, since their lesions were classified as involving both anterior quadrants to some extent.

Lesion site and extent were analyzed on CAT scans in two ways:

a) a general locus of lesion was documented (see Appendix 3).

b) a visual estimation of comparative size of lesion (Small, medium, large) was obtained (see Appendix 3).

Etiology

To ensure that subjects with focal vs more diffuse damage to the brain were selected, preference for inclusion in the study was given to patients with brain lesions secondary to vascular disease (e.g., hemorrhage, stroke). In particular, patients who suffered focal damage subsequent to strokes were preferred. Given limitations on patient availability, patients with intracranial growths were also included in the study, but only in their post-operative stage. Cases where tumors or surgery resulted in more diffuse brain damage or generalized problems (e.g., seizures) or where pathology had resulted from multiple events, were excluded from the study.

Chronicity

In order to eliminate cases still suffering from perifocal or extra-focal involvement, and thus ensuring that performance was more greatly attributable to the presence of a focal lesion, patients were seen at least six months post-injury or surgery.

General Procedure

Patient Group

Potential candidates for this group, who had been identified through referrals from physicians, were contacted by telephone by the author after physician approval (see Appendix 4). Of a total 68 patients identified, 33 agreed to participate in the study. Of the 35 who did not participate, eleven could not be reached, 5 were deceased or too ill to participate, and 19 declined to participate or failed to keep scheduled appointments.

During the first part of the initial appointment, medical histories were taken from the patients (see Appendix 5). The neuropsychological tests outlined above were administered to ensure that subjects met the required criteria (see Appendix 6), and consent forms were signed (see Appendix 7). Of the 33 who agreed to participate and were seen for the initial screening, 5 were too impaired to include in the study and 2 were dropped because, while fluent in English, they were primarily French speaking. The experimental tests described below were administered to the 26 remaining patients who fulfilled the required criteria. As discussed earlier, two

patients who did not receive the PPVT but who met all other neuropsychological criteria were included in the study.

On the basis of CAT scan analyses, 4 patients were subsequently dropped from the Patient Group since damage was found to be located primarily in subcortical structures. Thus, based on the above procedure, a total of 22 patients were included in the study. Neurological data for the final Patient group is presented in Appendix 8. Sequencing test data from the 4 patients with subcortical lesions are presented in Appendix 9A, 9B.

Control Group

Potential matches for each of the individuals in the patient groups were located through personal recruiting and contact with social agencies such as the Salvation Army, Senior Employment Centre and the YMCA. Control subjects with no history of neurological illness were matched to patients on the basis of sex, age (+ 5 years) and level of education (+ 2 years). In addition, PPVT was administered to provide a secondary control of intellectual abilities.

Control subjects were contacted and the purpose of the study and the extent of their involvement explained (see Appendix 10). Participants were seen in one session during which the experimental tasks and the PPVT were administered.

Experimental Tasks

General Description

Two sequencing tasks, each consisting of verbal and pictorial counterparts, were devised for this experiment. Each task consists of a series of cards depicting a sequence which is presented in a scrambled order; when put in proper order the cards make a grammatically correct sentence or depict a sequence of events.

Increasing Span Task

The first task was devised to examine the effects of increasing length on sequencing ability. Increasing sequences of 4, 6, 9 or 12 units were administered in verbal and pictorial counterparts of the task. For example,

verbal sequences would proceed from 4 unit series such as: "girl/that/well/sings" ("that girl sings well") to increasingly longer and more complex 12 unit series such as: "many/abroad/they/from/were/return/ the/spent/pleased/home/to/months" ("they were pleased to return home from the many months spent abroad" (see Appendix 11). Pictorial sequences would proceed from a 4 card depiction of a package being gift wrapped to increasingly longer sequences such as a 12 card depiction of 2 suitcases being systematically packed or unpacked (see Appendix 12). Thus, the manipulations for this task were:

A) Modality of Input - Verbal
- Pictorial

B) Sequence Length - 4, 6, 9, 12 units

Capture Error Task

The second task was designed to assess performance on serial tasks where conditions which may lead to capture errors are present. To create a potential for capture errors, each 6 unit sequence was created so that a special association existed between two successive units. This association is

based on the meaningful link between the units and/or frequent occurrence of the two units as a pair. For example, word pairs such as coffee cup, honey bee, red roses, full moon, have a strong semantic association. Pictures that depict actions which frequently follow one another are similarly 'associated'. For example, pictures of an alarm clock ringing and then being shut off; a car having a flat tire and then being repaired. These relatively strong and meaningful associations between two successive units of a sequence created the potential for capture errors in some sequences. This potential was created by manipulating the validity of the association so that sometimes they are valid and sometimes invalid in the context of the sequence (i.e., sometimes the cards should be placed together, other times they must be apart in the final solution). Some examples will demonstrate this manipulation. The following verbal series is presented: "of/full/the/was/coffee/cup". The association between coffee and cup must be broken in this instance for correct solution of this sequence "The/cup/was/full/of/coffee". In other instances, the association is valid and the words should be kept together as presented; for example, in the sequence "sky/the/lit/full/moon/a", full and moon belong together in the final solution, "A/full/moon/lit/the/sky". Sequences containing valid associations were called non-capture sequences; those containing

invalid associations, which must be broken, were called capture sequences (see Appendix 13). Sequences with valid and invalid associations were randomly presented with each subtest.

The notion of a potential for capture errors in the context of this study is based on the assumption that the successive pairs of words or pictures meant to create such potential are meaningfully linked and routinely associated with one another. While frequency lists exist for single words (e.g. Battig and Montague, 1969); there are no measures of frequency of successive pairs of words such as those used in the present study. Consequently, a specific questionnaire was created for this purpose. This questionnaire contained 60 word pairs which had to be rated with respect to strength of association on a scale of 1-5 (see Appendix 14). The word pairs were based on the actual stimuli of the verbal sequences included in the Capture Task. Three combinations of word pairs were derived from each of the twenty verbal sequences. One of these combinations was the associated pair (whether valid or invalid); the other two pairs were created using two words in the sequence (nouns, verbs, adverbs or adjectives). For example, for the sequence 'Fire engines sped to the accident' the following three word pairs were included in the questionnaire: the associated pair

'fire engines'; 'fire accident'; 'engines sped'. The three pairs derived from each sequence were presented one after the other on the questionnaire, to examine relative strength of associations between word pairs in the same sequence. The primary aim of the questionnaire, however, was to provide quantitative evidence that valid and invalid associations were judged to be equal in their strength of association.

The questionnaire was administered to a random group of 65 non brain-damaged male and female individuals. These individuals were English speaking adults between the ages of 18-66, who had no history of neurologic or psychiatric illness and who were not familiar with any other aspect of the present study. Results obtained from this normative sample were in the expected direction and are presented in Appendix 15. On the basis of these results, the stimuli included in the verbal subtest were judged to be valid in terms of the manipulation required in the task.

No pictorial counterpart to the verbal questionnaire was administered since it was felt that isolated pairs of pictures could not be differentially ranked for strength of association with any validity.

Stimuli similar to those described above for the verbal subtest were created in the pictorial sequences. For example, in one capture sequence a card depicts an alarm clock ringing, while the next card shows a hand shutting the same alarm clock off; however, in the final solution of the sequence, these two cards must be separated to accommodate several intervening steps depicted by the other cards (i.e., alarm rings, man sleepily picks up telephone believing it is ringing, when no one is on the line he heads for the front door, no one is there, looks around, realizes the alarm is causing the ringing, shuts it off) (see Appendix 16).

The inclusion of both valid and invalid associations were necessary to prevent the formation of set; i.e., if the associations were always invalid, the subjects may learn after a time that the words that seem to go together must be used apart every time.

In summary, the manipulations within this second task were the following:

A) Modality of Input - Verbal
- Pictorial

B) Validity of Associations - Correct
- Incorrect

Task Procedure

Patients who had met the neuropsychological criteria for inclusion in the study, and all controls, received 4 tests, i.e., the verbal and pictorial counterparts of both sequencing tasks. The order of administration of these 4 tests was completely randomized.

While criteria for performance on the neuropsychological battery had been established a priori, and had been used to determine eligibility for inclusion in the study, five patients who were ultimately included had not achieved all of the pre-established levels on some of the measures. These included two patients from the Anterior group and three from the

Posterior group and involved performance on such measures as immediate recognition of WMS figures, Digit Span and Token Test, though not all of these measures were lowered in any one patient. The decision to include these patients in the study was based on the fact that, aside from failing to reach criteria for 1 or 2 of these measures, their performance on the rest of the measures met a priori standards. No patient who failed to reach criteria on more than two measures, or whose performance on any test fell below criteria by more than 1 point, was included in the sample.

Increasing Span Task.

Verbal and pictorial subtests were administered separately. Each subtest contained a total of 12 sequences consisting of 4, 6, 9 or 12 words or pictures. Three trials per sequence length were administered. Sequences were administered in increasing order, beginning always at those containing 4 cards. The sequences of twelve units were administered only to subjects who correctly ordered 2 of the 3 sequences containing 9 cards.

For each sequence length (4,6,9,12) two dependent measures were obtained. Verbal and pictorial subtests were scored separately. Examples

of the calculations involved are presented in Appendix 17. The dependent measures were:

1) Total Time - The total amount of time, in seconds, required to complete all three trials of each length. No time limit was imposed on any trial administered. If a trial was not administered, as was the case for some 12 unit sequences, a maximum time score of 300 seconds was given since this was found to be the general upper limit for time taken to perform the longest sequences.

2) Percent of Correct Junctures - A juncture was defined as the joining between two adjacent units of a sequence. A correct juncture is the placement of two adjacent units in the correct order; each correct pair equals one correct juncture. For example, in a 4 unit sequence, A-B-C-D, the maximum number of correct junctures (*) is three: A*B*C*D - similarly, a six unit sequence contains 5 junctures, A*B*C*D*E*F, a nine unit sequence, 8 junctures and a twelve unit sequence, 11 junctures. For any sequence not attempted, a score of 0 was given. Four percentage scores were calculated, since the maximum score possible at each length

varied. Each score reflected the percentage of correct junctures obtained over the three trials at each length. Calculations were as follows:

e.g. 6 unit sequences:

Max. score = 5 correct junctures per trial x 3 trials

= 15 junctures

% Corr. junc = (# of correct junctures/15) X

100

Capture Error Task

Verbal and pictorial subtests were administered separately. The verbal subtest was made up of 20 sequences, 10 non-capture sequences which contained valid associations, 10 capture sequences which contained invalid associations. The pictorial counterpart contained 12 sequences, 6 non-capture sequences with valid associations, 6 capture sequences with invalid associations. All sequences in each subtest were administered, regardless of performance.

Dependent measures for this task were calculated separately both for verbal and pictorial subtests, as well as for capture and non-capture sequences. Thus 4 values were calculated for each of the dependent measures, one for each of the following subsets of sequences (verbal non-capture, verbal capture; pictorial non-capture, pictorial capture).

For the verbal subtest, values were calculated on the basis of 10 non-capture and 10 capture sequences. For the pictorial subtest values were based on 6 non-capture and 6 capture sequences. Examples of calculations involved for each of the following dependent measures are given in Appendix 18.

The dependent measures calculated are as follows:

1) Average Time - The total amount of time, in seconds, required to complete each subset of sequences, divided by the number of sequences in that subset.

2) Average Time of Capture - The total amount of time, across all sequences in a particular subset listed above, that the two units presented

as an associated pair were kept together during solution of the task, divided by the number of sequences in that subset.

3) Average Number of Correct Junctures - These were calculated as previously described in the preceding section. Maximum number of junctures available in each of the subsets of the verbal task (capture and non-capture) is 50 (5 junctures/seq. x 10 sequences). In the pictorial task, the maximum for each subset is 30 (5 junctures/seq. x 6 sequences). The average number of correct junctures was then calculated by dividing the total number of junctures obtained on all sequences of a subset by the number of sequences within that subset. As a result, a score ranging from 0-5 was possible for each subset.

4) Percent of Correct Sequences - Correct sequences, as defined above, were totalled across each of the 4 subsets. For the purpose of the quantitative analyses, these total scores were converted to percentages since verbal and pictorial subtests varied in the number of sequences (verbal, 10 non-capture; 10 capture; pictorial, 6 non-capture; 6 capture)

5) Capture Errors - When an invalid association was maintained in the final solution of a sequence, i.e., when 2 invalidly associated words were not taken apart during solution of the sequence and used separately, a capture error was assumed. Since these can only occur in capture sequences with invalid associations, a maximum of 10 capture errors were possible in the verbal subtest and six in the pictorial subtest. For the purpose of quantitative analyses, these values were also converted to percentages, so that verbal and pictorial values would be comparable.

Administration of Sequencing Tasks

Series of words or pictures were printed on 7.5 x 12 cm white cards. Printed numbers on the back of the cards (starting at the number 1) indicated the order for laying out the cards from the subject's left to right. Thus card #1 was the first one put down on the subject's left, #2 was next, then #3, etc. Letters starting at A and also printed on the back of the cards, provided the code for scoring. Thus, if a 6 unit sequence was ordered correctly, the letters on the back of the cards would be in sequence from A to F.

In all cases, the tasks began with the following instructions: "I have here a set of cards; each card has a word/picture on it. Here is the first set. When the cards are ordered a certain way the words make a complete sentence/show a complete story. Right now they are in the wrong order. Put them in order so they make a complete sentence/show a complete story. Work as quickly as you can and tell me when you have finished". Timing of performance began at this point and stopped when the subject indicated that he/she was finished. Time and order were recorded on the appropriate scoring forms. A maximum of two minutes was allowed to make an initial move during any trial; if no move was made during that time, the instructions were repeated. After one more minute, if the cards had still not been moved, the subject was asked if he/she was finished and the trial stopped. In such cases, a maximum of 300 seconds as a time score was given, with 0 correct junctures.

Analyses

The following group comparisons were made using analysis of variance. Age and IQ level differences between groups were analyzed. For each of the sequencing tasks, three sets of comparisons were carried out: 1) Anterior group versus their Control group; 2) Posterior group versus their

Control group; 3) Anterior group versus Posterior group. While multivariate analyses are most appropriate in carrying out comparisons among several groups, univariate analyses were used in the present study for the following reasons: first, the hypotheses in this study were directed and specific and the goal was to isolate specific frontal lobe deficits. Second, variability within patients is a major concern in such studies. Brain-damaged populations are known to have variable results; in addition, sample sizes in studies such as this tend to be relatively small. Univariate analyses were chosen to minimize the effects of that variability. Nonetheless, it is important to note that the use of univariate analyses with multiple means may affect alpha levels. Results obtained under such conditions must be interpreted with caution. All significant results were verified using the Conservative Geisser-Greenhouse Test (Kirk, 1982). Results were considered significant if they exceeded $p < 0.05$.

Post-hoc comparisons were performed using the Newman-Keuls method (Kirk, 1982) in cases where sample sizes were equal (i.e., where each patient group was compared to its own control group) and the Tukey-Kramer method (Kirk, 1982) in cases where sample sizes were unequal (i.e., when anterior and posterior patient groups were compared).

Increasing Span Task. Split-plot ANOVAs were performed on subject scores for Percent of Correct Junctures. Presence or locus of lesion was the group factor while length of sequence was the within-subject factor. This resulted in a 2 (Group) X 3 (Length) design for this variable. One-way ANOVAs were used to determine group differences in Total Time at each sequence length.

Capture Error Task. For each set of comparisons outlined above, Split-plot ANOVAs were performed on subject scores. Presence or locus of lesion was the group factor while validity of association between units was the within-subject factor. This resulted in a 2 (Group) X 2 (Correct/Incorrect) design for the following dependent variables: Average Time, Average Time of Capture, Average Number of Correct Junctures and Percent of Correct Sequences. A one-way ANOVA was used to determine group differences in number of Capture Errors, since these involved only capture sequences (where invalid associations were present).

RESULTS

Subjects

Group means were calculated for patient and control groups for age, education and PPVT scores. Results are outlined in Table 1. Significant differences were found between the Posterior Group and their Control Group on PPVT scores $F(1,15)=5.14, p=.039$. As a result, further comparisons between these two groups were carried out using PPVT as a covariate. In order not to forfeit the data from the patient in the Posterior group who had not been administered the PPVT, the mean PPVT score of the Posterior group replaced this patient's missing value in further analyses. Comparisons were also carried out within the Patient Group between patients with anterior vs posterior lesions on age, education and PPVT scores (see Table 1), as well as on all neuropsychological data obtained with the screening battery (see Table 2). Results of these comparisons indicated no significant differences between patients on any of the above measures.

Table 1

Demographic Data for Patient and Control Groups

Variable	Patients				Controls			
	Anterior		Posterior		Anterior[1]		Posterior	
	M	SD	M	SD	M	SD	M	SD
Age	44.2 (N=13)	12.0	48.7 (N=9)	11.7	42.8 (N=13)	12.8	48.8 (N=9)	11.2
Educ	14.5 (N=13)	4.0	12.4 (N=9)	3.5	14.9 (N=13)	4.0	13.4 (N=9)	4.2
PPVT	127.2 (N=12)	14.0	112.5 (N=8)	19.5	129.1 (N=13)	9.2	129.7 (N=9)	11.0
Sex	F=3	M=10	F=5	M=4	F=3	M=10	F=5	M=4

[1]The terms Anterior and Posterior were used for the Control Subjects to denote the Patient group with which they were matched.

Table 2

Neuropsychological Test Results

Variable	Anterior Patients			Posterior Patients		
	M	SD		M	SD	
Weschler Reproductions Multiple Choice Scale (Immediate)	3.2	0.9		3.4	0.7	
(Delayed)	3.2	1.0		3.3	0.7	
Count by three's Trial 1 (Time)	24.2	21.0		17.9	7.4	
(Errors)	0.4	0.7		0.1	0.3	
Count by three's Trial 2 (Time)	18.0	6.1	(n=4)	26.0	0.0	(n=1)
(Errors)	0.8	0.5		0.0	0.0	
Count to twenty (Time)	13.3	15.0		9.2	3.7	
(Errors)	0.0	0.0		0.0	0.0	
Digit Span - Longest Span	5.4	0.7		5.3	0.9	
Word Recognition	8.0	0.0		8.0	0.0	
Word Picture Matching	10.0	0.0		10.0	0.0	
Token Test	15.5	0.7		15.3	0.7	
	(n=13)			(n=9)		

Experimental Tasks

Results for the two sequencing tasks will be presented separately: first, the Increasing Span Sequencing Task; second, the Capture Task. For each of the tasks, results of the comparisons between each of the patient groups and their control group will be discussed first. Additional comparisons between anterior and posterior patients will follow. Descriptive data from subjects according to lesions in one of the defined brain quadrants will then be presented.

Increasing Span Task

No differences between patient and control groups were found on this task when their performance on sequences of 4 units was compared. Since performance of all groups was at an equivalently high level (90%-100% correct), with minimal variance, these results were excluded from further comparison.

Anterior patients took significantly more time than their control group to arrange 9 unit sequences [$F(1,24)=9.05, p=.006$] and 12 unit sequences

[$F(1,24)=7.65, p=.011$] overall (see Table 3). In addition, significant differences in the performance of the two groups were found at all sequence lengths (see Table 3), with anterior patients obtaining significantly fewer junctures correct on sequences of 6, 9 and 12 units overall [$F(1,24)=4.74, p=.039$] (see Figure 1).

In contrast, a group X length interaction [$F(2,32)=4.5, p=.019$] revealed that significant differences in performance between the Posterior patient group and their control group occurred only on the percent of correct junctures obtained for longer sequences (9 & 12 units) (see Figure 1). Posterior patients were also slower than their control group on 9 unit sequences [$F(1,15)=6.87, p=.019$].

In summary, the results indicate that anterior patients exhibit more widespread difficulties on the sequencing tasks, with deficits occurring even on sequences of 6 units.

When the anterior and posterior groups were directly compared, group differences were observed only on the amount of time taken on 9 unit

Table 3

Results of Patient and Control Groups for Increasing Span Task

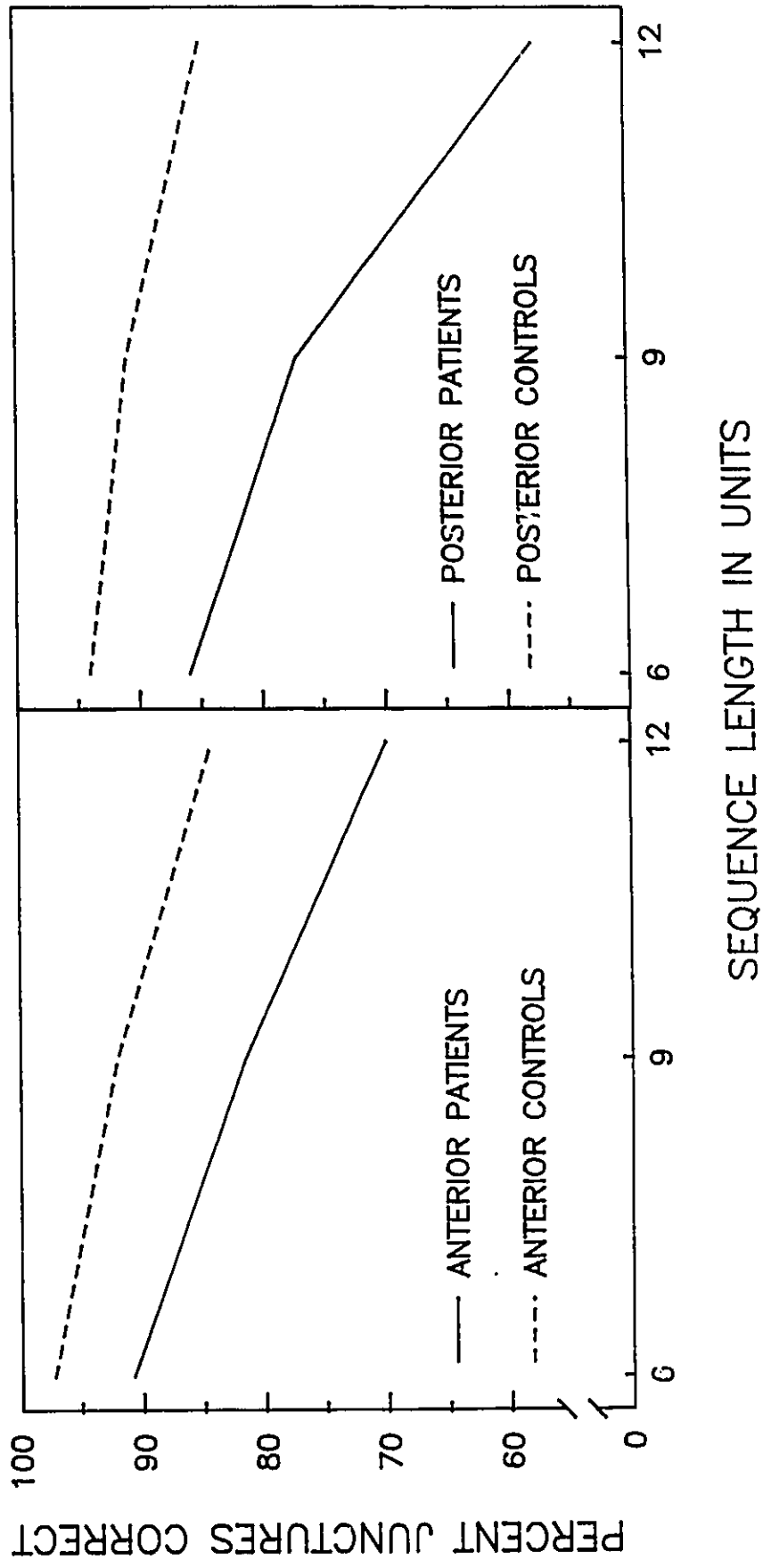
Span Length in units	6		9		12	
	M	SD	M	SD	M	SD
Anterior Patients N=13						
TT (a)	103.54	69.78	209.85	98.74	464.04	206.05
%CJ (b)	90.77	9.50	81.57	21.07	69.93	23.27
Controls N=13						
TT	63.31	21.04	123.46	31.02	289.27	97.11
%CJ	97.18	4.48	91.99	6.07	84.15	9.13
Posterior Patients N=9						
TT	99.39	41.68	345.56	133.73	427.06	109.11
%CJ	85.93	12.78	77.08	21.97	57.58	23.36
Controls N=9						
TT	70.06	39.37	177.33	74.37	305.00	103.96
%CJ	94.07	7.41	90.97	6.91	84.85	12.26

a) TT = Total time in seconds to complete three trials at each sequence length

b) %CJ= Percent of correct junctures obtained over three trials of each sequence length

Figure 1. Percent Junctures Correct obtained on 6, 9 and 12 unit sequences of the Increasing Span Task. Anterior patients and their control group on left, Posterior patients and their control group on right.

Figure 1.


PERCENT JUNCTURES CORRECT
100
90
80
70
60
0
1
6
9
12
6
9
12
SEQUENCE LENGTH IN UNITS
ANTERIOR PATIENTS
ANTERIOR CONTROLS
POSTERIOR PATIENTS
POSTERIOR CONTROLS

sequences, with posterior patients taking more time to complete these sequences [$F(1,20)=7.53, p=.012$].

Capture Error Task

Comparisons were carried out between each patient group and its own control. Based on these comparisons, there was some indication of specific anterior deficits on this task. Anterior patients took significantly more time than their control group to complete sequences overall $F(1,24)=8.0, p=.009$, and kept associated units together longer, whether the association was valid or invalid [$F(1,24)=7.65, p=.011$]. Furthermore, they tended to obtain lower results in the final solution of the task. While not significantly different at established levels, a comparison of the percent correct sequences obtained by anterior patients versus their control group approached significance with anterior patients obtaining fewer correct sequences overall [$F(1,24)=4.01, p=.057$] (see Table 4).

When posterior patients were compared to their control group, a significant Group X Correct interaction was found for Average Time of Capture [$F(1,16)=8.44, p=.01$]. Post-hoc comparisons revealed that

Table 4

Results of Patient and Control Groups for Capture Error Task

	Anterior Patients				Controls			
	Non-Capture		Capture		Non-Capture		Capture	
	M	SD	M	SD	M	SD	M	SD
a) AT	34.14	13.44	44.20	21.58	21.67	5.23	28.25	7.65
b) ATC	29.79	11.49	26.69	12.71	21.02	5.39	15.67	6.47
c) ACJ	4.32	0.57	3.89	0.63	4.59	0.31	4.32	0.49
d) %CS	76.03	17.23	62.82	21.37	84.87	10.13	78.59	16.13
e) NCE			0.92	0.70			0.65	0.52
	Posterior Patients				Controls			
AT	34.08	13.70	46.46	21.22	22.73	6.08	29.74	13.87
ATC	30.71	12.47	32.06	15.25	21.98	6.50	13.57	5.04
ACJ	4.26	0.62	3.98	0.64	4.29	0.39	4.43	0.55
%CS	71.29	23.50	70.00	18.35	74.63	13.48	80.19	18.77
NCE			1.11	0.65			0.44	0.81

a) Average time
b) Average time of capture
c) Average number correct junctures
d) Percent correct sequences
e) Number of capture errors

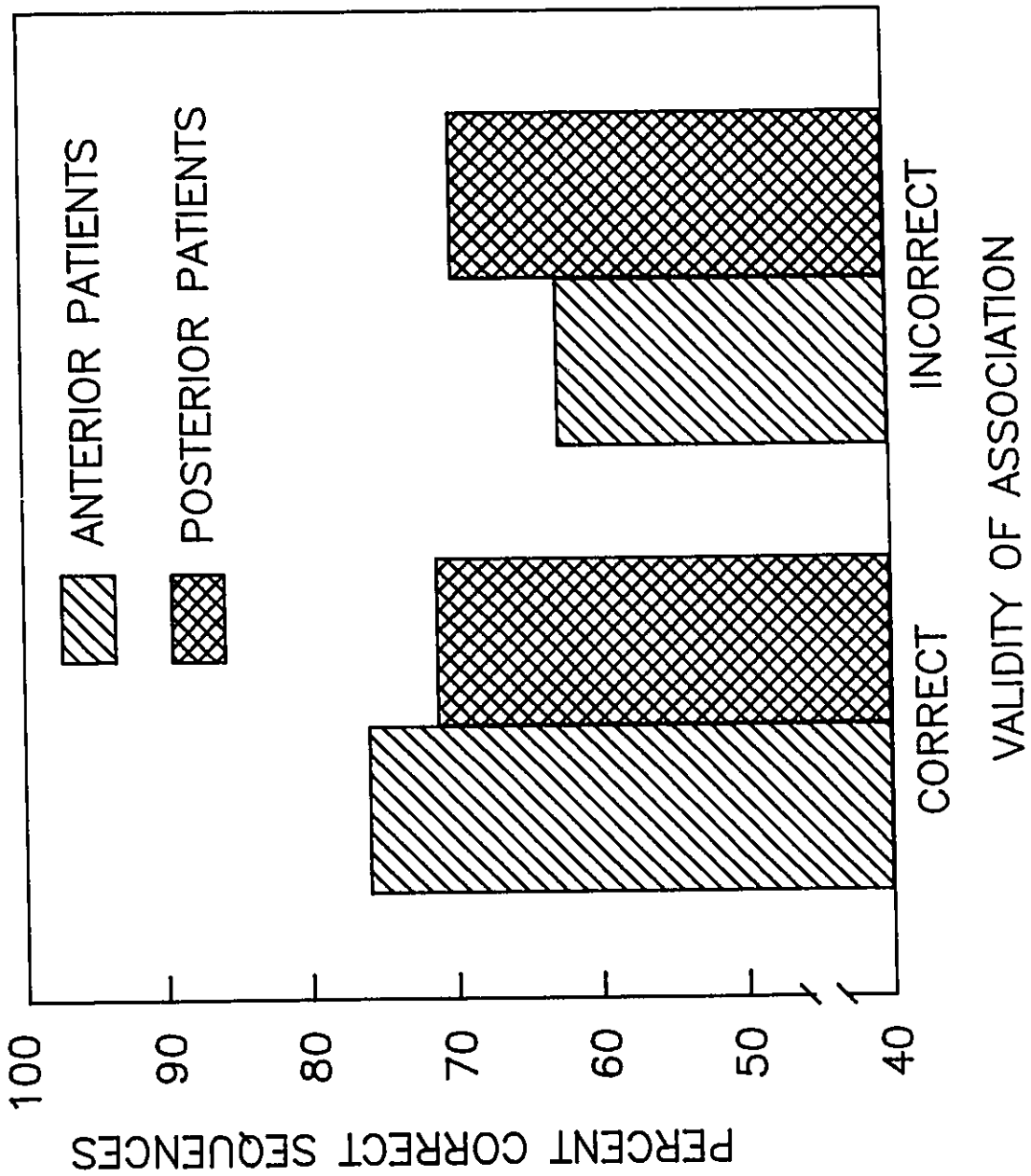
posterior patients kept associated units together longer than their control group, when the associations were both valid or invalid. No significant differences were found between these two groups on number of correct junctures and percent of correct sequences, or on time taken to complete the sequences overall.

When comparisons were carried out between anterior and posterior brain-lesioned patients the relation between lesion location and performance on this task is even more evident. Results indicated no differences between the groups in terms of time measures or number of capture errors. A significant Group X Correct interaction revealed, however, that posterior patients obtained significantly more correct sequences than anterior patients on capture sequences, where associations were invalid [$F(1,20)=4.22, p=.05$] (see Figure 2).

In sum, the patient groups appear to be equivalent in many respects. Very specific differences, however, apparently dependent on lesion location occurred. Only anterior patients made more sequencing errors where solution involved breaking invalid associated pairs.

Figure 2. Percent of Correct Sequences obtained on the Capture Error Task by Anterior and Posterior patients when associations between two successsive units in the sequences were valid or invalid.

Figure 2.


ANTERIOR PATIENTS
POSTERIOR PATIENTS
PERCENT CORRECT SEQUENCES
100
90
80
70
60
50
40
CORRECT
INCORRECT
VALIDITY OF ASSOCIATION

Descriptive Results of Quadrant Comparisons

Descriptive analyses were carried out to compare the performance of patients when these were grouped according to quadrant of lesion. Patients were assigned to one of 4 groups based on the criteria outlined in Appendix 3. These groups were as follows: Left Anterior, N=3; Left Posterior, N=5; Right Anterior, N=8; Right Posterior, N=4. For each of the sequencing tasks, results from right and left anterior patients will be presented first, followed by those for left and right posterior groups. Verbal and pictorial subtests will be considered separately in these analyses.

Increasing Span Task

On both verbal and pictorial subtests of this task, qualitative analyses indicated problems for left anterior patients when compared to the right anterior group. As sequences increased in length, Left Anterior patients generally took more time to solve the task (see Figure 3) while the percent of correct junctures they obtained showed a consistent and larger decline than that of Right Anterior patients (see Figure 4).

Figure 3. Total time, in seconds, taken by Right and Left Anterior patients to complete 6, 9 and 12 unit sequences of the Increasing Span Task. Verbal subtest results are presented on the left, pictorial subtest results on the right.

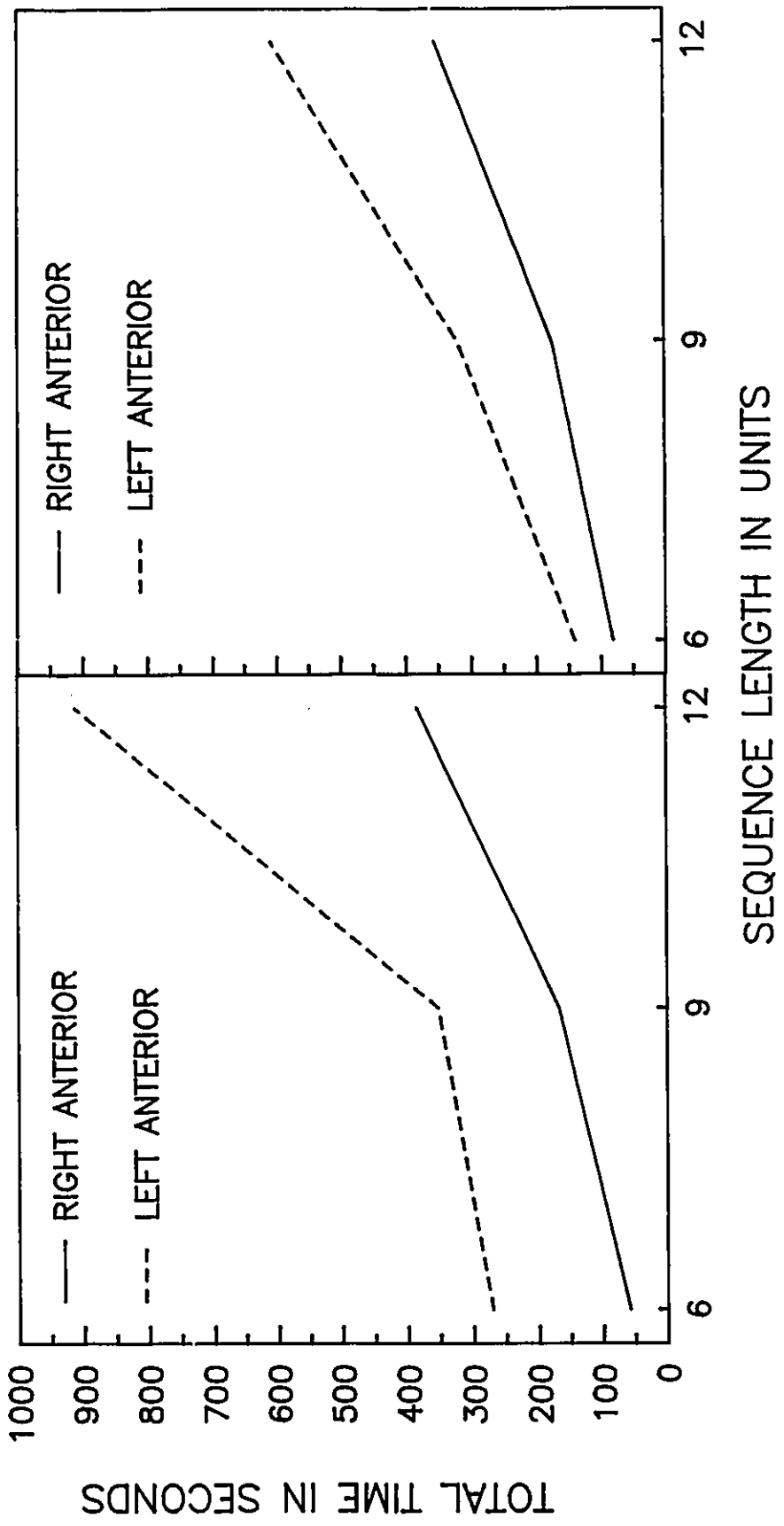

VERBAL
PICTORIAL
RIGHT ANTERIOR
LEFT ANTERIOR
TOTAL TIME IN SECONDS
1000
900
800
700
600
500
400
300
200
100
0
6
9
12
SEQUENCE LENGTH IN UNITS

Figure 3.

Figure 4. Percent Junctures Correct obtained by Right and Left Anterior patients on 6, 9 and 12 unit sequences of the Increasing Span Task. Verbal subtest results are presented on the left, pictorial subtest results on the right.

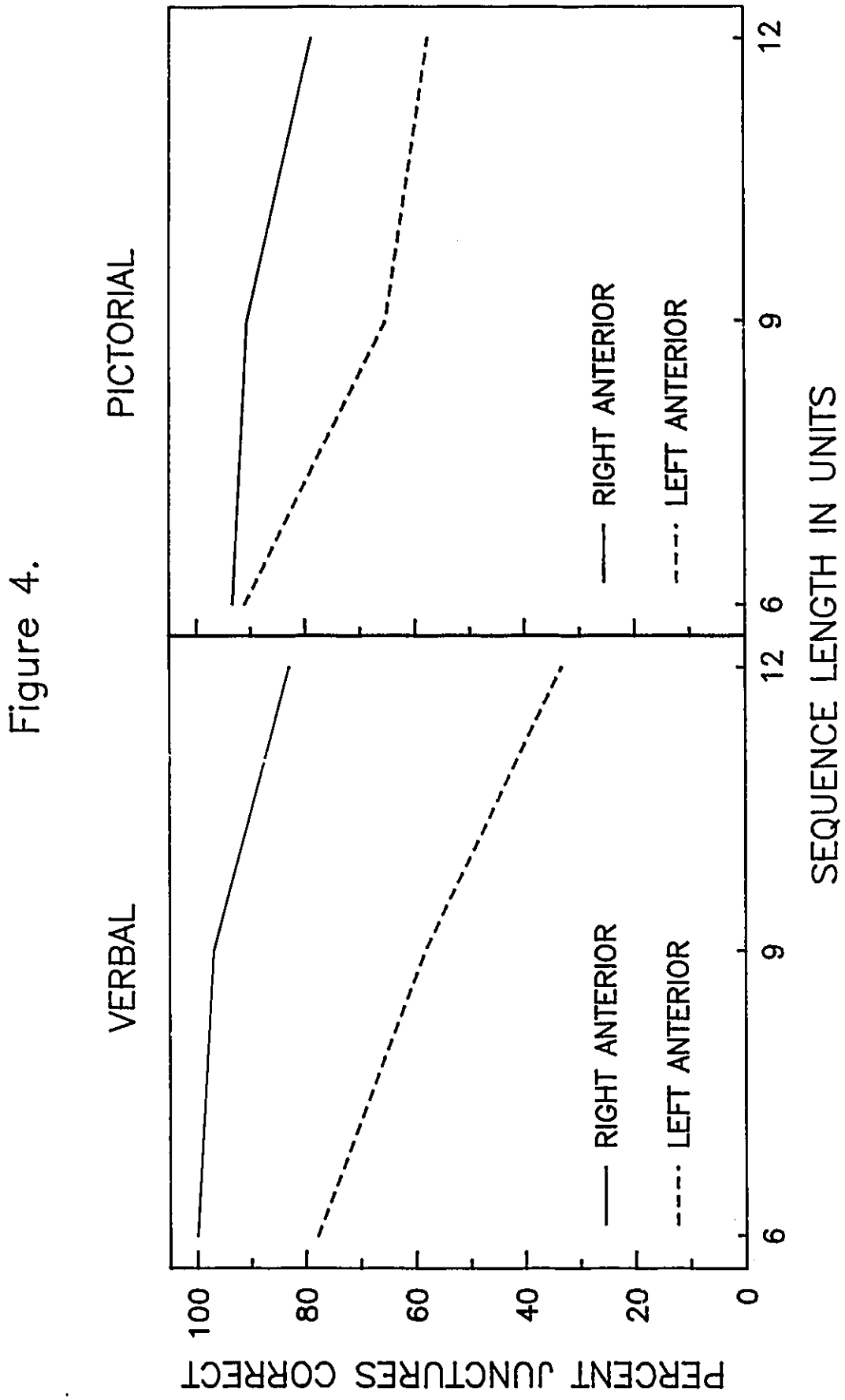

VERBAL
PICTORIAL
RIGHT ANTERIOR
LEFT ANTERIOR
PERCENT JUNCTURES CORRECT
100
80
60
40
20
0
6
9
12
SEQUENCE LENGTH IN UNITS

Figure 4.

In contrast to this, more consistent, pattern of left hemisphere deficits observed in the anterior group, the performance of the two posterior groups was not as clear cut. While Left Posterior patients generally took longer to complete both verbal and pictorial sequences (see Figure 5), it was the Right Posterior group which showed lower performance scores (see Figure 6).

Capture Error Task

In the anterior group descriptive analyses again revealed selective difficulties in the performance of Left Anterior patients, particularly in capture sequences, where a potential for capture error was present. This group took longer to perform both verbal and pictorial subtests than Right Anterior patients (see Figure 7). Furthermore, they obtained fewer correct junctures and fewer correct sequences, primarily for verbal sequences, where the associated pairs were invalid (see Figure 8).

In verbal and pictorial sequences where associations were valid, a double dissociation was observed in the performance of Right Anterior and Left Anterior patients. Right Anterior patients obtained more sequences

Figure 5. Total time, in seconds, taken by Right and Left Posterior patients to complete 6, 9 and 12 unit sequences of the Increasing Span Task. Verbal subtest results are presented on the left, pictorial subtest results on the right.

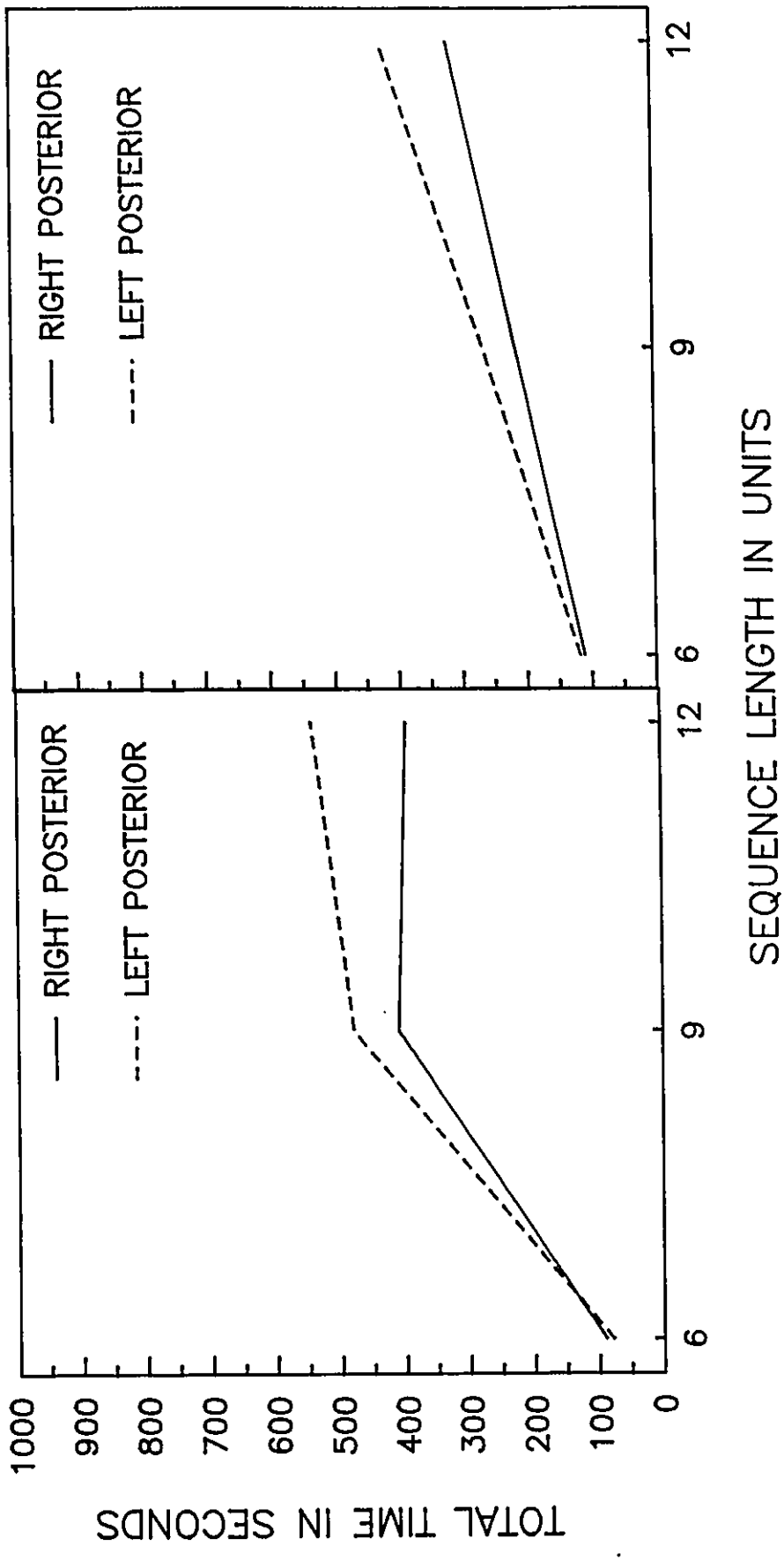

VERBAL
PICTORIAL
RIGHT POSTERIOR
LEFT POSTERIOR
RIGHT POSTERIOR
LEFT POSTERIOR
TOTAL TIME IN SECONDS
1000
900
800
700
600
500
400
300
200
100
0
6
9
12
6
9
12
SEQUENCE LENGTH IN UNITS

Figure 5.

Figure 6. Percent Junctures Correct obtained by Right and Left Posterior patients on 6, 9 and 12 unit sequences of the Increasing Span Task. Verbal subtest results are presented on the left, pictorial subtest results on the right.

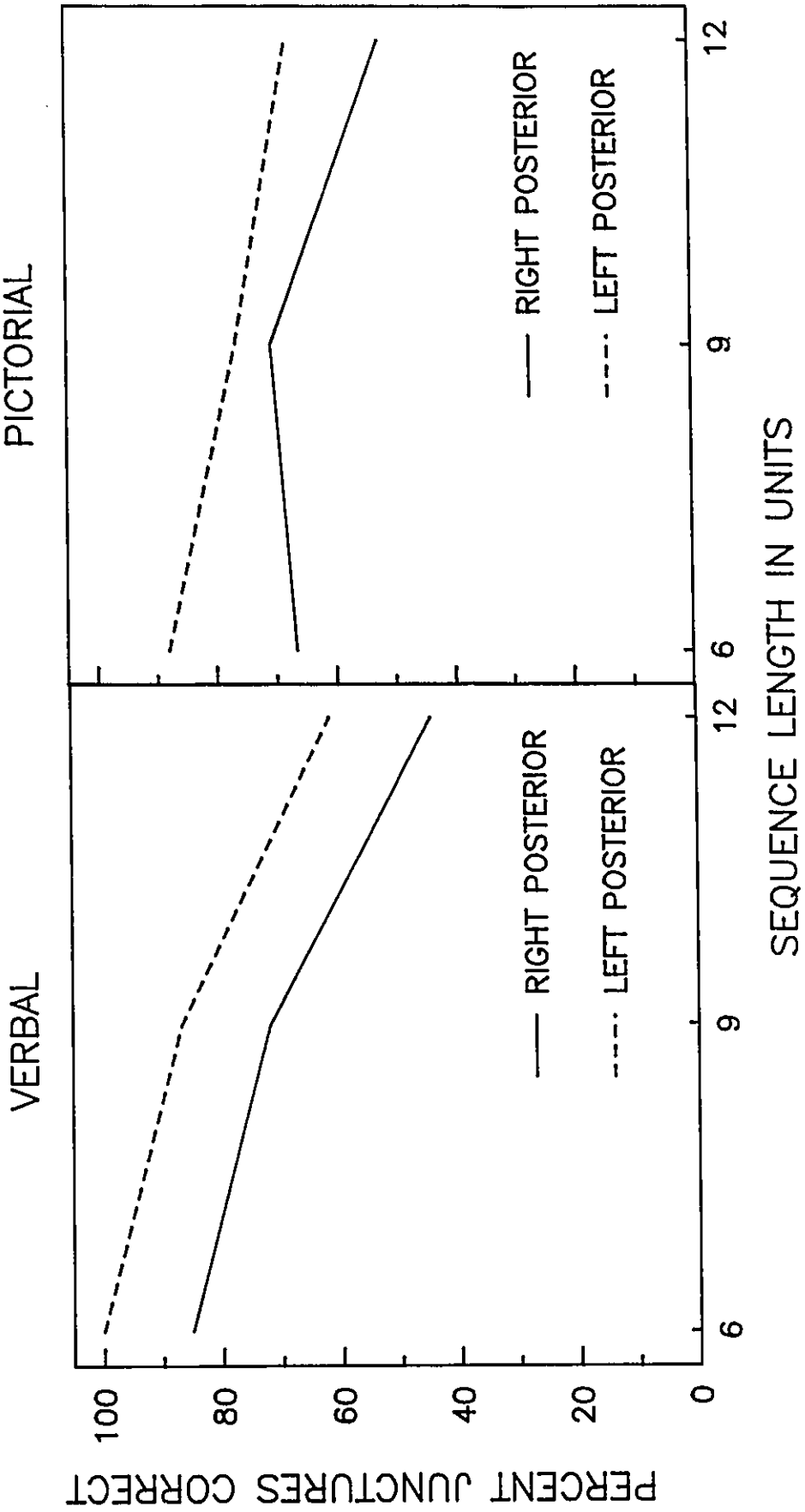

VERBAL
PICTORIAL
RIGHT POSTERIOR
LEFT POSTERIOR
RIGHT POSTERIOR
LEFT POSTERIOR
PERCENT JUNCTURES CORRECT
100
80
60
40
20
0
6
9
12
6
9
12
SEQUENCE LENGTH IN UNITS

Figure 6.

Figure 7. Average time, in seconds, taken to complete sequences on the Capture Error Task by Right and Left Anterior and Posterior patients when associations between two successive units in the sequences were valid or invalid. Verbal subtest results are presented on the left, pictorial subtest results on the right.

Figure 7.

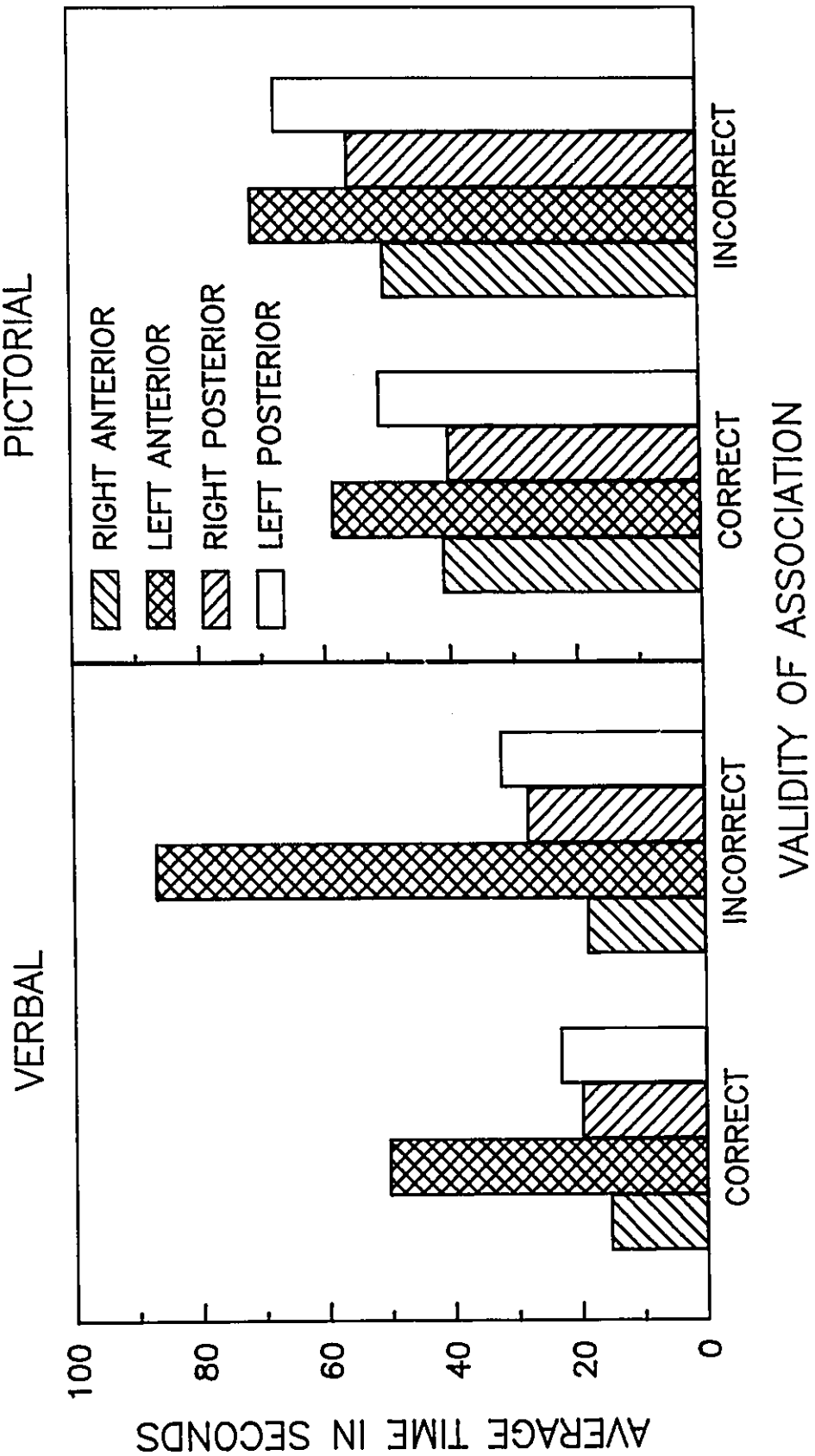
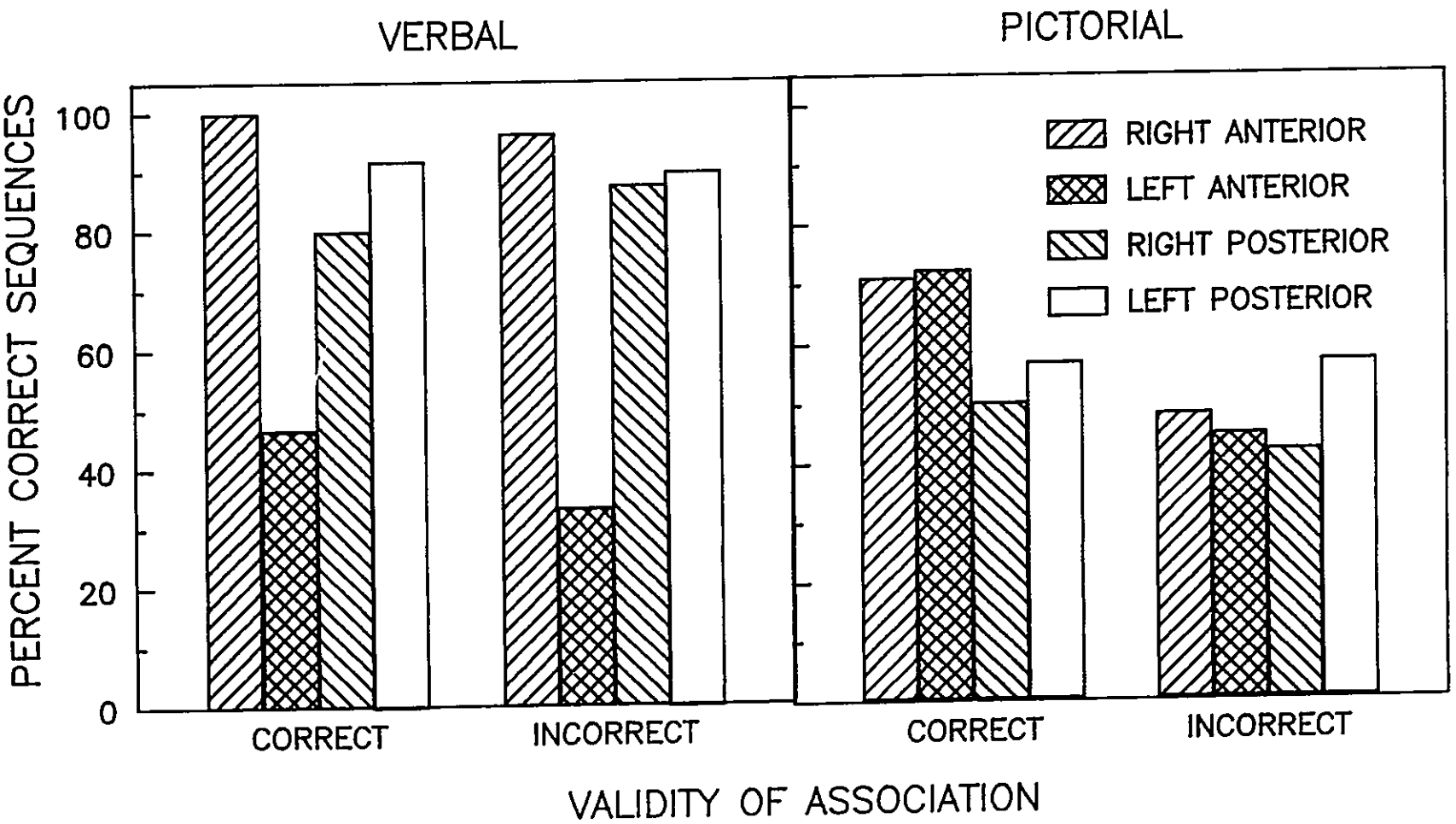

PICTORIAL
VERBAL
RIGHT ANTERIOR
LEFT ANTERIOR
RIGHT POSTERIOR
LEFT POSTERIOR
CORRECT
INCORRECT
CORRECT
INCORRECT
VALIDITY OF ASSOCIATION
AVERAGE TIME IN SECONDS
0
20
40
60
80
100

Figure 8. Percent of Correct Sequences obtained on the Capture Error Task by Right and Left, Anterior and Posterior patients when associations between two successive units sequences were valid or invalid. Verbal subtest results are presented on the left, pictorial subtest results on the right.

Figure 8.


VERBAL
PICTORIAL
PERCENT CORRECT SEQUENCES
100
80
60
40
20
0
RIGHT ANTERIOR
LEFT ANTERIOR
RIGHT POSTERIOR
LEFT POSTERIOR
CORRECT
INCORRECT
CORRECT
INCORRECT
VALIDITY OF ASSOCIATION

correct overall on the verbal subtest, whereas Left Anterior patients obtained somewhat higher scores on the pictorial subtest (see Figure 8).

In the posterior group, differences in performance between right and left hemisphere patients followed a similar pattern as that found in the Increasing Span Task. Left Posterior patients generally took more time to complete verbal and pictorial subtests than Right Posterior patients (see Figure 7), whether verbal or pictorial, though they performed better or as well as Right Posterior patients on all the tests (see Figure 8).

DISCUSSION

Disorders of sequencing have been suggested as an integral feature of frontal lobe functioning (Stuss & Benson, 1986). The present study addressed the question of sequencing ability after frontal damage. This was done by isolating two factors: 1) complexity, defined by length of the task; 2) the presence of strong routine associations. The effect of these two factors on the control of on-going serial tasks was examined. Results generally indicated that the performance of patients with focal frontal lobe lesions was significantly inferior to normal control subjects and patients with posterior lesions under these two conditions. The results and their relevance are now discussed in greater detail.

Subjects

Efforts had been made to gather a larger number of patients. Sixty-eight patients were originally identified as potential candidates for the study. To control for possible confounding variables detracting from the validity of the results, criteria were operationally defined and included: age, language, neurologic and psychiatric history and lesion location. Due

to reluctance to participate or ability to pass the stringent criteria, 22 subjects remained for study (13 with anterior brain lesions, 9 with posterior brain lesions). The final group represents a sample which is well defined along several important criteria, a factor which strengthens the validity of the results obtained.

Patient and control groups were matched on age and level of education. These groups did not differ in levels of intellectual ability as measured by the PPVT (Patient group X=121.3, SD=17.5; Control group X=129.3, SD=9.7) As a result the two groups can be considered equivalent in these important respects.

No differences were found on the neuropsychological criteria between Anterior and Posterior patients. All patients had the basic ability to perform the sequencing tasks, as demonstrated by their strong performance on the 4 unit sequences of the Increasing Span Test. Posterior patients tended to be older than Anterior patients. Evidence in the literature supports a relationship between age and site of CVA (Holland, 1980) corresponding to those in this study.

Although differences in IQ scores were not significantly different between the Anterior and Posterior groups, Posterior patients tended to obtain lower scores. Several reasons can account for this: a) the Posterior patients were older than Anterior patients; b) education levels, though not significantly different, tended to be lower in the Posterior group; c) lesions in posterior regions tend to cause depressed IQ scores in comparison to anterior lesions (Stuss & Benson, 1986; Teuber, 1959).

Patients with focal lesions resulting from vascular accidents were preferred for inclusion in this study. Nonetheless, due to limitations in patient availability, patients with lesions of different etiologies were also included. A number of factors, such as neuropathology, anatomical boundary, rate of onset and duration are involved in the manifestations of brain lesions. Etiology has implications for all of these. For example, infarcts will generally result in lesions which conform to the vascular distribution of a particular vessel and will affect much of the tissue in that area whereas tumors do not conform to such distribution and will affect different tissues. The importance of these issues cannot be underestimated. The limitations of differences in lesion parameters in the present study must be recognized. Nonetheless, several important points must be

emphasized when considering the results. First, different etiologies were relatively evenly distributed among the patient groups, as were lesion sizes, so that selective effects of such factors on performance of a particular patient group may be reasonably ruled out. Furthermore, lesion localization was made on the best available data from CAT scan data and clinical signs.

A notable point regarding the brain-damaged patients seen for this study is that, with only one exception, the Anterior patients did not appear strikingly different from the Posterior group in terms of behavior during testing, or strategic approach to the experimental tasks. With the exception of patient P.C. who had bilateral frontal lesions and was apathetic and unconcerned during the test session, patients from the Anterior group did not exhibit overt "frontal" behaviors such as disorganized approach to the task, failure to use feedback, lack of motivation and so on. All patients appeared to carry out the task with effort, strive for correct solutions and make changes when solutions appeared incorrect. No one left sequences in the original order of presentation. Several factors may contribute to this finding. The first is that the lesions of patients included in this study were focal lesions of generally small to moderate extension. A second reason may be the amount of structure of both the general testing session and

each specific sequence task. Demands and procedure were very clear and very limited. The patients were required only to move the presented cards into a sequential array. A high degree of structure has been postulated as having striking effects on the performance of patients with Anterior lesions. (Stuss & Benson, 1986).

In sum, there were no striking behavioral differences between Anterior and Posterior patient groups noted within the testing sessions. Specific experimental manipulations based on hypotheses derived from the literature, however, did reveal significant differences between the two groups.

Finally, subjects included in this study adhered to stringent criteria and were closely matched. Within patients, Anterior and Posterior patients were matched on age, intellectual ability and level of education. Patient and control groups were matched on age, level of education and intellectual ability. A significant difference in intellectual ability between the Posterior Group and their Control Group was controlled statistically to eliminate possible confounding effects.

Experimental Tasks

Increasing Span Task

Several important results emerge from analyses of performance on this task. The first is that patients with anterior lesions showed no difficulty in organizing short sequences. This negative result is consistent with several findings examining frontal deficits on various sequencing tasks. Petrides and Milner (1982) found no deficits in frontal lobe patients on short versions of a subject ordered pointing task. Shallice (1982), using the Tower of Hanoi test, found no impairment on tasks requiring only 2 or 3 steps. Digit Span does not appear to be dramatically affected by frontal damage (Stuss, Benson, Kaplan, Weir & Della Malva, 1981). Stuss et al. (1983) administered the WAIS Picture Arrangement subtest to three groups of schizophrenics who had undergone bilateral prefrontal leucotomy 25 years earlier. The test was divided into simple (first four) and complex (last four) items. Frontal patients had no difficulty on simple items though there was a significant difference from the normal control group on the more complex items. Thus, in these patients, the establishment of logical sequences appears to be intact at least at a simple, baseline level.

A second major finding in the present study is that all patients with brain lesions, whether anterior or posterior, were vulnerable to the characteristics of the Increasing Span Task. Thus length, as used in this study to define complexity, does not appear selectively to affect the performance of patients with frontal lobe lesions.

Length of sequence plays some role in performance: for example, there is a difference between 4 and 6-12 unit sequences in brain-lesioned patients. Nonetheless, this difference is found among both groups of patients and may reflect the sensitivity of the longer sequences to brain-damage in general.

This result is not inconsistent with some views found in recent literature. Fuster (1985), for example, suggests that not all behaviors, however long, fall within the domain of the prefrontal cortex. Fuster excludes well-established and stereotyped sequences of behavior (e.g., our morning routine) where one act leads automatically to the next and where temporal discontinuities (e.g., the wait for the bus) do not impose a cognitive challenge. Performance at this level may be seen as a lower order of control or organization (Shallice, 1988), indicative of non-frontal

sub-processes (Stuss and Benson, 1986). This type of control is primarily invariant, guided more by external sensory stimuli and discrete obvious changes in the environment. In this type of context, the brain follows rather than prescribes the order (Fuster, 1985).

While some evidence in the literature does suggest that longer sequential tasks may be impaired after frontal damage, the present results indicate that length per se is not the salient feature bringing the selective difficulties about. It may be that in those tasks longer sequences indirectly generated other demands which require frontal lobe input.

Fuster (1985), in defining the agenda of the prefrontal cortex, refers to structures of behavior in which temporal discontiguities, whether self imposed or imposed by external forces, separate environmental events from the actions they determine, or the actions from the goals they pursue. It may be that during longer sequential tasks, subjects are required to budge such temporal gaps.

Another characteristic of tasks which appear to call upon frontal input is an element of ambiguity. Frontal lesions appear to affect behaviors

which are incompletely specified by the environmental situation, i.e., where the context in which the behavior occurs is ambiguous, or where several alternatives are possible (Pribram, 1973; Pribram & Tubbs, 1967). According to Brody and Pribram (1978) the frontal cortex is involved with a higher order control essential for perceiving the reliable aspects of stimuli and allowing for flexible response patterns in a variable context. These researchers examined the role of anterior frontal cortex in monkeys on sequencing tasks which were a) externally organized by specific rules for solution, and b) where internal organization was needed in the absence of rules to guide behavior. They found that the frontal group was impaired in learning both types of sequences, but that this impairment was not noted in lesioned monkeys who had acquired extensive testing experience or who had learned the specific sequencing problems. Brody and Pribram concluded that frontal ablations made the monkeys less able to integrate or compensate for variable features of the task and that sophistication with respect to the testing method or the specific tasks predisposed the monkeys to restrict their own alternatives.

Thus, the less environmental structure available during a task, and the greater the number of alternatives of behavior possible, the greater the

dependence on the frontal lobes for the imposition of structure and organization. It may be that sequential tasks indirectly generate demands for such structure and organization. As a greater number of sequential units must be dealt with, the context of the sequence becomes more difficult to maintain or determine. More alternatives are generated and more details must be dealt with.

In sum, it has been postulated in recent literature that specific characteristics must be inherent in a task in order for that task to require frontal input. The findings obtained on the increasing span sequences suggest that length of sequence per se is not one such characteristic. Both Frontal and Posterior patients performed the most simple (4 unit) sequences as efficiently as normal controls. Once sequences surpassed this basic level, however, deficits appeared in the performance of both patient groups.

In relation to the frontal lobes, the present findings and discussion have two implications. At one level, sequencing may involve relatively simple or overlearned routines; at another, it may be involved in a more supervisory, organizational role, required when tasks involve more complex demands.

Deficits seen on longer sequential tasks in other studies may not be due directly to length per se, but rather may arise from other demands, indirectly generated by increasing length, which require greater supervision and organization.

Capture Error Task

Analysis of performance on the Capture Error Task revealed statistically significant results. Anterior patients were more affected by the presence of conditions which could lead to capture errors.

Differences between anterior patients and their control group in terms of correct sequences obtained approached significance, with anterior patients obtaining fewer sequences correct. Furthermore, anterior patients differed significantly from posterior patients in their ability to arrange sequences correctly when a potential for capture error was present (i.e., where the association between the units presented together was invalid).

The effects noted cannot be attributed to three apparent factors. First, differences between the two patient groups cannot be attributed to differences in time taken to complete the task (i.e., impulsivity or slowness). No differences between the two groups were noted on time taken to complete the task. Second, the effects cannot be attributed to brain damage in general since the impairment is primarily seen in the frontal lobe patients. Finally, based on CAT scan observations, there is no indication that anterior patients as a group had larger lesions than posterior patients.

Fuster (1985) has hypothesized that, the more novel the event or action, the greater the role of the prefrontal cortex. The term novel is used by Fuster to apply to actions or events which, even though not new to the individual, are unpredictable or unforseen. These events or actions have a low probability of occurrence in the context in which behavior takes place or compete with others which have a high probability of occurrence in the same context. Thus novelty, in this respect, is a relative concept. The events or actions in question are novel with respect to other probable alternatives.

The manipulations of the Capture Error Task, particularly in instances where associations are invalid, create the conditions similar to those that Fuster describes. The deficits of frontal lobe patients exhibited in sequences containing invalid associations, in the face of good performance when associations were valid emphasize the unique quality of the frontal lobe input in this particular sequencing task. Pairs of words which are closely associated (e.g., first aid; honey bees) or pictures that apparently define an action and its logical consequence (alarm rings, is shut off; hammer poised to hit a nail, hammer hitting the nail) might be considered by the subject as having a high probability of belonging together. These, however, must be taken apart and used in a less characteristic way in the correct context of the sequence.

Fusters's view of the necessity of frontal input under the above conditions is not incompatible with the Norman and Shallice (1986) model of a Supervisory System. In this model, the conditions which necessitate the input of the SS are those in which, for example, strong environmental triggers activate associations and routine solutions which are inappropriate in a particular context. Much of behavior involves routine, familiar or automatic behaviors which fall under the domain of contention scheduling.

This component selects schemas on the basis of strength of activating environmental triggers and directs efforts and cognitive resources in a routine way. When the situation requires that selection of routinely associated behaviors be overriden, the SS intervenes and activates 'general planning schemas'. These schemas direct well-learned information or skills in novel, more flexible ways, in order to achieve accurate solutions. If the SS is in some way inoperative, behavior may lapse more easily under the control of contention scheduling.

On the basis of this model, the frontal deficits seen on this particular task could be explained. Patients with frontal lesions would be more susceptible to the influence of the associated pairs contained in each sequence. When the association between the pairs is invalid, a specific demand for intervention by the frontal lobes is created. What appears as a strong and likely association between two words or pictures must be broken, requiring flexibility. Each unit must be used separately and in an initially unforseen way. If the system for overriding the routine association is inoperative, solution of the task could revert more easily to a system which places greater emphasis on the strength of associations. Thus, when the association is incorrect, impaired frontal input could result in more

capture errors and less correct sequences overall. This is what was observed in the present study.

Descriptive Quadrant Comparisons

In establishing this research project, it had been hoped that patient availability would allow examination of lesion specificity, in particular to isolate hemispheric differences. While much effort was invested in obtaining larger and more equivalent groups, final numbers fell below attempted levels. In additon, etiology was not necessarily equivalent among groups. Nevertheless, because of the original intent, it was decided to present available data on hemispheric differences descriptively. Results must be cautiously interpreted.

Discussion of descriptive analyses of performance on the Increasing Span Task will be presented first, followed by that for the Capture Error Task. Comparisons between four patient groups will be reported. Anterior and Posterior brain-damaged groups were divided according to hemisphere of lesion, based on CAT scan results. The four groups were as follows: 1) Right Frontal (N=8); 2) Left Frontal (N=3); 3) Right Posterior (N=4); 4)

Left Posterior (N=5). Because of the direction of this research project, emphasis here will be placed primarily on the comparison between Right and Left Anterior groups.

In general, the descriptive observations suggest that Left Anterior patients had the greatest difficulty overall for both verbal and pictorial Increasing Span tests. Their performance was generally the slowest across the four groups. Their performance (in terms of number of correct junctures) was the most impaired across the four groups on the verbal sequences and generally as low as that of Right Posterior patients on pictorial sequences. In sharp contrast, the performance of Right Anterior patients was the fastest and most accurate on both subtests across the four groups.

Two related results emerge from this descriptive analysis. First, Left Anterior patients are the most impaired group on this task, while Right Anterior patients have the best performance overall. Second, the Left Anterior problems extend across verbal and pictorial subtests. These findings suggest a left hemisphere dominance, within anterior brain regions, for sequential tasks, regardless of material. This hypothesis is supported by

various studies in the literature. The left hemisphere has been implicated in temporal sequential information processing in memory tasks (DeRenzi, Faglioni & Villa, 1977). Verbal codes have been hypothesized as being essential where the serial order of item presentation must be retained (where items include concrete pictures and meaningless forms) (Del Castillo & Gumenik, 1972; Nelson, Brooks & Borden, 1973; Paivio & Csapo, 1969). Shallice (1982), using the Tower of Hanoi Test, reported that left anterior patients were slower and had more incorrect responses once problems required more than just direct moves.

The findings of this study contrast with those obtained by Hamsher and Roberts (1985) on two sequencing tasks where subjects were required to arrange 6 cards with names or photographs of recent U.S. presidents by order of office. Hamsher and Roberts found that 45% of patients with focal right hemisphere lesions manifested a sequencing deficit (i.e., failed to arrange names and photographs accurately despite knowledge of names or faces during naming task) compared to 13% in the left sided group. It is difficult to compare these results with the present findings, however, since no data outlining locus or extent of lesion was provided by the authors.

The present results indicating greater Left Anterior deficits on the Increasing Span Task also appear to be in possible conflict with results reported by Milner (1982). Milner used two tasks in her study. The first, Subject-Ordered Pointing Task, included a series of cards on each of which was the same set of stimuli, but with the position of the stimuli varying randomly from card to card. The subject had to go through the cards pointing to one stimulus on each card without pointing to any item more than once. Milner found that left anterior patients had difficulty on this task and hypothesized that the task involves programming of voluntary actions. The second, Recency Discrimination Task, involved a pack of cards on each of which two stimuli are presented. From time to time, a card appeared bearing two stimuli with a question mark between them and the subject had to say which of the two stimuli he saw most recently. This task was hypothesized to require monitoring a sequence of externally ordered events. Milner reported primarily right anterior deficits on this test.

At first glance one might expect, on the basis of Milner's interpretation, that right frontal patients in this study should have more difficulty with the Increasing Span Task, since the order of the sequences is externally provided and subjects are not required to impose an arbitrary order of

their own. When the task is analyzed, however, and compared to Milner's 'externally-ordered' task, namely Recency Discrimination, some striking differences between the two become apparent. First, while there is an inherent order in the Increasing Span sequences, a certain degree of subjective ordering is necessary. Correct solution involves a complex process of multi-step planning and organization, reassessment at various stages of solution and monitoring of ongoing actions. Second, the present task is more complex than Milner's in that it involves handling more than just two items at a time. Third, Milner's task involves very restricted demands of discrimination of temporal order between two items. On the basis of these differences, it appears that the present task, while containing an externally imposed order, is more similar in its demands to Milner's Subject-Ordered Pointing Task which required subjective organization and monitoring of a sequential task.

The present results support the hypothesis that left frontal regions are primarily involved in supervisory control and organizational processes. The left hemisphere has long been known to have the dominant role in the control of voluntary actions (Luria, 1973; Shallice, 1988). It is left hemisphere lesions, for example, that give rise to apraxia (Kimura &

Archibald, 1974). The hypothesis of a selective link between left frontal regions and organizational control processes is consistent with the findings on the Increasing Span Task that after left frontal lesions, deficits arise whatever the nature of the material - words or pictorial representations.

Results of the present analysis also have implications relating to issues in material specificity and hemispheric asymmetry. It is generally believed that the frontal lobes follow left-verbal/right-non-verbal hemsipheric asymmetries (Stuss & Benson, 1983). Based on this hypothesis, verbal and pictorial counterparts were devised for the tasks in this study. Sensory modality was controlled by presenting all sequences visually. Results indicated, however, that left frontal patients had difficulty with both verbal and pictorial sequences and that right frontal patients had in fact the best performance on pictorial sequences of all patient groups.

Several explanations for these seemingly contradictory findings may be possible. First, a closer examination of the material contained in the present pictorial sequences reveals that, while these are made up of linear drawings, they are not necessarily non-verbal. The organization of the sequences relies heavily on a logical "story" depicted by the series of scenes.

Absence of words does not necessarily make a stimulus "non-verbal". Meaningful pictorial representations may be verbally labelled (Lezak, 1983). In addition, some verbal information is contained within certain pictorial sequences (e.g. labels, road signs, directions etc.) which serves as a cue for correct placement of specific cards.

The performance of right frontal patients on the pictorial subtest of this task stands in contrast to that reported by McFie and Piercy (1952) on the Picture Arrangement Test (PA) (Wechsler, 1981). According to these authors, right frontal patients showed the greatest impairment on the PA and tended to leave the pictures in the presented order. The PA has come to be generally regarded as sensitive to right frontal damage.

It could be argued that differences observed in the overall performance of these two similar tasks (Pictorial Increasing Span & PA) may be due to differences in materials. The Increasing Span pictorial task perhaps contains more 'verbal' content, thereby relying more heavily on left hemisphere resources. The data, however, supporting the link between right frontal regions and performance on the PA must also be carefully scrutinized. Closer examination of other findings reveals that, while the

right hemisphere remains heavily implicated in PA performance, the right temporal regions appear to have a greater impact on PA scores (McFie, 1960; Meier & French, 1966; McFie & Thomson, 1972; Reitman, 1959). The performance of the right posterior group in the pictorial tasks of the present study supports the suggestion that posterior right hemisphere regions are more involved in such tasks. In sum, the present results suggest that the association between performance on the PA test and right frontal regions must be carefully re-evaluated.

A second reason which may underlie the contrasting findings on material specificity and hemispheric asymmetry in sequencing tasks relates to task demands. Evidence suggests that tasks which rely on a high degree of subjective organization and monitoring during solution selectively involve left anterior areas. Both verbal and pictorial subtests of the Increasing Span Task may be considered to involve such demands. From this perspective, the present results can be considered comparable to those of Shallice (1982) and Milner and Petrides (1982) on their sequencing tasks.

Differences in hemispheric processing may be a third factor underlying the contrasting results on hemispheric asymmetry. It has been hypothesized

that each hemisphere is organized differently and that there exist two qualitatively different types of hemispheric processing. The left hemipshere is characterized by serial analytic processes concerned with categorical features and details whereas the right hemiphere is concerned with holistic configurational processes (Veroff, 1978). This model is important in that it implicates two modes of processing beyond sensory modality and verbal-nonverbal content.

Veroff (1978) found that left hemisphere lesions affected the performance of pictorial sequences where information is carried in features and details whereas right hemisphere lesions interfered with the performance of pictorial sequences which involved spatial relationships.

The finding that left anterior patients had greater difficulty with both verbal and pictorial subtests of the Increasing Span Task may be interpreted on the basis of this conceptual approach. Many of the pictorial sequences require analysis of internal features in order to understand the story depicted. If such an analysis relies on left hemisphere processing regardless of material and sensory modality, then left-sided deficits would be expected on this task.

It appears that at least two separate factors must be considered in relation to hemispheric asymmetries in the present paradigm: a) verbal-nonverbal material; b) differences in hemispheric processing. Overall, the sequences in the present study did not clearly separate these factors. Their content appears to rely most heavily on left hemiphere processes.

The descriptive results obtained from the quadrant analysis of performance on the Capture Error Task provide further support that the left frontal regions may be more selectively involved in supervisory, control processes. Left frontal patients were slowest on both verbal and pictorial subtests of this task; their performance was generally lower, although not as striking for pictorial information.

In sum, while there may be some influence of verbal content, these data and other research suggest a primary role of left frontal regions in the organization of control processes in sequencing tasks as defined by this paradigm.

Overview

The results of the present study can be summarized in the following way. First, none of the patients had difficulty in organizing short sequences. Second, all patients with focal lesions appear to be sensitive to sequencing tasks at normal span and beyond, though the effect is not attributable to increasing length alone. Third, anterior patients differed from their control group and from posterior patients in their ability to arrange sequences correctly when a potential for capture errors was present.

The finding that frontal patients, as a group had no difficulty organizing short sequences but were impaired when specific experimental interventions were present (i.e., the presence of a potential for capture errors) indicates that sequencing ability may be conceptualized as a multi-modal process. At least two types, or levels, of sequencing are implied by the present results. These are labeled for ease of recognition as subordinate and superordinate sequencing.

Subordinate sequencing is the ability, reflected in the excellent performance by all subjects in the 4 unit sequencing task, to perform

sequencing tasks that are automatic or relatively simple for a particular individual. This sequencing ability, intact even in the presence of frontal lobe damage, is represented in the contention schedules of Shallice (1988) or the posterior basal functional systems described by Stuss and Benson (1986).

Impaired subordinate sequencing may occur when brain damage is present in those regions subserving contention schedules or making up a posterior-basal functional system. For example, impaired sequencing ability has been reported after hippocampal damage (Kimble and Pribram, 1963).

Superordinate sequencing, on the other hand, is by its very nature dependent on subordinate sequencing. That is, once a deficit in subordinate sequencing is present, it would be difficult to differentiate a deficit in superordinate sequencing. In contrast, damage to the superordinate sequencing process would not affect subordinate sequencing. Superordinate sequencing appears to be dependent on intact frontal lobes. In a general sense, circumstances which require frontal input during serial tasks (i.e., create superordinate demands) are situations which require creative, step

by step, non-automatic solutions, where goals are not directly attainable but require strategic planning and on-going monitoring of responses.

One characteristic of superordinate sequencing suggested by the present study is its specificity to particular task demands. Specific circumstances exist which generate superordinate demands and require selective frontal lobe involvement. The range of these circumstances has yet to be clearly established. At least one condition indicated by the present study is the presence of competing alternatives, suggested by the Capture Error Task.

The hypothesis that competition between alternatives generates superordinate demands and, consequently, presents frontal lobe patients with unique problems, has some practical ramifications. Characteristic frontal difficulties in sustaining directed behavioral and mental acts may be alleviated by manipulating different factors.

One factor may be the degree of differentiation of environmental cues. Norman and Shallice (1986) have suggested that when two actions share similar characteristics, the trigger conditions appropriate for one are likely

to be appropriate for another. Chances of incorrect schemas being activated are greater in such circumstances. By creating greater differentiation in cues associated with specific tasks, frontal patients' vulnerability to inappropriate or ambiguous environmental stimuli may be alleviated. Repeated experience with a particular task may be one way to provide a better defined context. Degree of learning and sophistication are relevant to the degree of involvement required by the frontal lobes.

General Issues

Differences in etiology of lesion may be an interactive factor in the present study since it included both vascular and tumor patients. In choosing subjects for this study, preference was given to patients with brain lesions secondary to vascular disease, particularly stroke. Limitations on availability of such patients made it necessary to include patients with intracranial growths. As already discussed, lesions resulting from tumors differ from those subsequent to vascular disease in terms of anatomy and neuropathology. Furthermore, different types of tumors affect brain tissue differently. Two types of tumors were represented in the Patient group. Meningioma, is a benign tumor originating from the meninges. As such it is

sharply demarcated from brain tissue and exerts pressure effects as it expands. Astrocytoma on the other hand, is an infiltrating tumor which destroys brain tissue as it spreads, with potentially more devastating effects on the brain.

Patients with lesions secondary to tumors were seen only in their post-operative stage, at least 6 months after surgery. Patients in whom tumors or surgery resulted in any diffuse damage or long-standing, generalized problems (e.g. seizure disorders etc.) were not included in the study. The issue of multiple etiologies must be considered when interpreting the data.

A second interactive factor in this study is the presence of some residual aphasic symtomatology in two of the left anterior patients included in the study. It may be argued that such symtomatology may be at least partially responsible for the findings that left anterior patients generally experience greater difficulty than right anterior patients on the experimental tasks. While this cannot be completely ruled out as a contributing factor, several issues suggest that impaired left anterior

performance on the sequencing tasks cannot simply be attributed to aphasic symtomatology.

The first is that in the present study, the performance of left anterior patients was at least equivalent and often lower than that of right anterior patients on pictorial tasks. The second relevant issue is the indication in the literature that various sequencing deficits exist in patients with anterior aphasias in addition to the inability to handle sequences of verbal material. While these patients routinely recognized single lexical items (e.g., point to a named object), they fail to handle sequences of items (e.g., point to three or more objects in sequence) (Albert, 1972; Benson, 1979; Luria, 1966); furthermore, they often fail to carry out multi-step commands, cannot reproduce sequences in drawing or motor activities and cannot replicate a tapped-out rhythm (Stuss & Benson, 1986). Studies investigating sequencing as it applies to language forms have suggested that frontal lesions can produce sequencing disturbances even in the absence of other major language problems (Albert, 1972; Samuels & Benson, 1979). Nonetheless, the results obtained in the present study must be interpreted cautiously and all the above factors must be comprehensively considered.

Discussion of some statistical issues is also relevant here. The Bonferroni statistic was calculated on the basis of the number of comparisons planned. Results of these calculations revealed that significance levels should be set at $p < .001$. While several findings did reach significance at this level of alpha, others would have been lost. Because this study is essentially a clinical one and may serve as a direction for future research, it is reasonable to use the generally accepted level of $p < .05$, though it is important to note that many of the present significant findings hovered closer to a $p < .01$ level of significance. All results were tested using the Adjusted Geisser-Greenhouse test which guards against violation of the assumption of singularity. This is important in a repeated measures design where the Within Subject Error term is frequently confounded.

Clinical studies often have difficulty obtaining sample size desirable for statistical analyses, and affect the power of the analyses. Given the actual sample size, caution in interpreting the present results is necessary. The study serves as a directive base for future studies. The results obtained are consistent with previous research. This reliability of results adds strength to the new findings reported.

In addition to limited availability of patients, the final sample size was somewhat smaller than hoped for because very stringent exclusion criteria were adhered to. These included a specified level of baseline abilities, adequate fluency in English, variables dealing with locus and extent of lesion (cortical versus subcortical, focal versus diffuse) lack of longstanding neurological or psychiatric history etc. The exclusion criteria reduced the number of potential candidates for the study and resulted in fewer subjects overall. However, adherence to such criteria ensured to the maximum degree possible that the positive findings could be attributed to focal brain lesions. There has been a trend in neuropsychological research for individual case studies as a basis for valid inferences about the structure of cognitive mechanisms in brain-damaged individuals (Caramazza, 1986; Caramazza & Badecker, 1989; Caramazza & McCloskey, 1988). Others have argued that the group versus single case study debate is not relevant (Zurif, Gardner & Brownell, 1989). While the present study cannot be perceived as a single case study design, one may extrapolate that smaller group analyses cannot be rejected. They provide the base for further experimental analyses. It is recommended that future research on the frontal lobes include a larger number of subjects and that issues such as locus and site of lesion, as well as etiology, be carefully considered in light

of the growing body of knowledge regarding the heterogeneity of anterior brain regions. Because of individual variability, individual analyses may be useful.

Some tests generally regarded as measures of sequencing ability do exist (e.g. Picture Arrangement subtest - WAIS-R (Weschler, 1981); Kaufman ABC's Test (Kaufman & Kaufman, 1983)). None of these, however, were specifically created to assess sequencing ability after frontal lesions in adults. The fact that the present tasks were devised for such a purpose and are based on evolving clinical and theoretical principles regarding the frontal lobes distinguishes them from other tasks currently in use. Nonetheless, while the present tasks go further than others in examining some characteristics of frontal lobe input in sequencing, aspects of test construction are relevant in this discussion. The sequencing tasks devised for this study, particularly the Capture Error Task, appear promising as assessment tools and warrant further development. An item analysis could be used to refine the tools, isolate more discriminating sequences and provide consistency in difficulty levels. The tests could be further developed to include pictorial sequences which rely much more on visuospatial components and are less 'verbal'. This would enhance the

examination of hemispheric differences. Furthermore, sequences which require subjective ordering should be developed and added to the tests, so that comparisons between these two aspects of sequencing may be examined with this particular paradigm.

Issues in Brain Organization

Although the term 'frontal lobes' was used throughout this paper, it is important to point out that emphasis is placed on the functional concept rather than on the specific localization. The brain is not strictly organized according to structural aspects such as lobes. Conceptually, the brain is regarded as being organized in systems. Each system represents a broad functional entity such as language, memory, attention and so on, with frontal and adjoining regions playing a greater or lesser role depending on task demands (Stuss & Benson, 1986).

Due to its anatomical connections, frontal regions hold a pre-eminent role in the organization of brain abilities. When talking about the frontal lobes, frontal 'systems' are actually being implied. Nevertheless, research

has indicated that focal frontal lesions are prominent in eliciting 'frontal dysfunction'.

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Appendix 1

Neurological Report

1. Date of Onset (must be at least 6 months post):

2. Nature of Illness (basis of present referral):

3. Date of Neurological Examination

4. Neurological Exam

	A. Cranial Nerves	B. Motor		C. Sensory	
I		R	L	R	L
II					
III					
IV					
VI					
VII		Notes		Notes	
VIII					
IX					
X					
XI					
XII					

5. CT scan (at least 6 months post-injury):

A1		A2	
i)	Date Performed:	i)	Date:
ii)	Type (with or without contrast):	ii)	Type:
iii)	Result:	iii)	Result:

6. Neglect:

Behavioral Observations (describe)

Tests for DSS - Visual R L L R B R R B L B L B

7. Scoring

i) Quadrant: (describe) LA RA LP RP

ii) Size: Small Medium Large

Copy Obtained Y N

8. EEG - date & report for each EEG carried out

i)

ii)

iii)

9. Inattention Y N

10. Apraxia: Oral Y N
Limb Y N

11. Surgery

i) Etiology (describe e.g. grade & type of tumor; infiltrating or not; involvement of other areas):

ii) How approached:

iii) Post-op. Complications

12. Other Relevant Medical History

Appendix 2

Criteria for CT Scan

Lesions classified by:

1) Quadrants: Fissure of Rolando designated as the anterior-posterior line of demarcation; central sulcus as left-right demarcation 75% of pathology to one quadrant essential for placement in one of the following: left anterior; right anterior; left posterior; right posterior. In case of tumors, there must be no compression of the midline and 75% of the tumor must be present in one side (total composite lesion to be considered).

2) Size:

A visual estimation, based on clinical judgement, will be used to classify lesions as small, medium or large.

Appendix 3

Lesion Data

PATIENT NAME: _____

DATE: _____

ASSESSED BY: _____

1. Extent of Lesion
(Fill in clinical estimation of percentage of lesion at each site)

Lobe	Side	Cortex	Subcortical (White Matter)	Deep Nuclei
Frontal Lobe	R	%	%	%
	L	%	%	%
Temporal Lobe	R	%	%	%
	L	%	%	%
Parietal Lobe	R	%	%	%
	L	%	%	%
Occipital Lobe	R	%	%	%
	L	%	%	%

2. Quadrant of Lesion (on basis of above; minimum 75% of pathology must be in one quadrant.

3. Size (circle appropriate on basis of clinical judgement)

S M L

Appendix 4

Script for Initial Contact with Patients

We are presently carrying out a study investigating the relationship between brain functioning and neuropsychological tasks. Neuropsychological tests are measurements of various functions such as attention, language, sequencing and so forth. In particular, we are investigating the ability to put information in logical order. All tests are question and answer, and do not involve any physical discomfort.

The study consists of two phases. In the initial phase you will be required to undergo a brief neurological-neuropsychological screening and give a short medical history which will take about 30 minutes of your time. Following this, you may be asked to undergo a second session of neuropsychological tests lasting about 1 1/2 hours. In addition, you may be asked to have a CAT scan.

Your cooperation will assist us in various ways. First, you will help advance basic science. Second, this knowledge will be useful to us in order to help others who have experienced neurological problems such as yours. Although all information is confidential, the general data will be used for research and publication purposes.

Appendix 5

Medical History

Patient _____

Examiner _____

Date _____

Informant _____

Referred by _____

Age _____

Education _____

Occupation _____

Marital Status _____

Eyesight (glasses etc.) _____

Hearing _____

Use of tobacco: amount _____ duration _____

Alcohol: amount _____ duration _____

Drugs _____ duration _____

Medication _____ duration _____
_____ duration _____
_____ duration _____

History

1. Is there any history of neurologic illness in your family?

2. Give a description of the circumstances and symptoms of your (stroke, tumor, aneurysm).

3. Have you any previous history of neurologic illness?

4. Have you ever had a closed head injury?

   a) when?

   b) how long unconscious?

   c) how long hospitalized?

5. Have you ever had motor weakness? If so, what side? Why? How long?

6. Have you ever had sensory loss? If so, what side? Why? How long?

7. Have you ever had a major operation? Were there any complications?

8. Have you ever been to see a psychologist or psychiatrist for extended treatment?

9. Are there any other neurological disorders you would like to tell me about?

Appendix 6

Neuropsychological Battery

Patient _____
Date _____

1. WMS Drawings (circle if choice correct)

Immediate Recall: 1 2 3 4
Delayed Recall: 1 2 3 4
(Criterion = 3/4 correct)

2a. Counting by 3's

-- -- -- -- -- -- -- -- -- -- -- -- -- --
1 4 7 10 13 16 19 22 25 28 31 34 37 40

Time: _____
Errors: _____

2b. Counting by 3's (trial 2)

-- -- -- -- -- -- -- -- -- -- -- -- -- --
1 4 7 10 13 16 19 22 25 28 31 34 37 40

Time: _____
Errors: _____

3a. Counting Backwards

$\overline{20}$ $\overline{19}$ $\overline{18}$ $\overline{17}$ $\overline{16}$ $\overline{15}$ $\overline{14}$ $\overline{13}$ $\overline{12}$ $\overline{11}$ $\overline{10}$ $\overline{9}$ $\overline{8}$ $\overline{7}$ $\overline{6}$ $\overline{5}$ $\overline{4}$ $\overline{3}$ $\overline{2}$ $\overline{1}$

Time: _____
Errors: _____

3b. Counting Backwards (Trial 2)

$\overline{20}$ $\overline{19}$ $\overline{18}$ $\overline{17}$ $\overline{16}$ $\overline{15}$ $\overline{14}$ $\overline{13}$ $\overline{12}$ $\overline{11}$ $\overline{10}$ $\overline{9}$ $\overline{8}$ $\overline{7}$ $\overline{6}$ $\overline{5}$ $\overline{4}$ $\overline{3}$ $\overline{2}$ $\overline{1}$

Time: _____
Errors: _____

Digit Span

582: 6439: 42731: 619473:
694: 7286: 75836: 392487:

(at least 1 trial of 5 passed)

Word Recognition: /8
Word-Picture Matching: /10

Appendix 7

Patient's Consent Form

NAME OF STUDY: Sequencing in Frontal Lobe Patients

PATIENT'S NAME: _____

ADDRESS: _____

_____

_____

I, _____, agree to participate in the above study and hereby authorize _____

_____

to proceed with the following examinations:

1. Neurological Examination, CT scan
2. Short series of neuropsychological tests

I have received a detailed explanation of the examinations to be conducted and studies to be given and I understand their nature and purpose.

I have been given an opportunity to ask questions regarding the examinations and studies involved and the questions which I have asked have been answered adequately. I have been told that I am able to withdraw my consent and to stop participation in the study at any time and for any reason without any effect on my medical care. All information will be confidential.

DATE: _____

PATIENT'S SIGNATURE: _____

WITNESS: _____
(Investigator)

WITNESS: _____

Appendix 8

Neurological Data for the Patient Group

Subject	Etiology	Extent	CT Location	Neurological Findings
Right Anterior				
1. R.K.	Right anterior MCA stroke	Moderate	Cortex, subcortical white matter & basal ganglia	Dense left hemiparesis Left hemi-sensory deficit Some residual deficits at time of testing
2. L.P.	Subarachnoid hemorrhage	Small	Right anterior midbrain, lateral to ventricles, with some temporal extension	Transient left arm drift; decreased light touch on left
3. T.H.	Meningioma	Small	Cortical, anterior superior-lateral tumor	None
4. R.M.	Grade II astrocytoma	Large	Frontal cortical to subcortical extension to lateral ventricle	None
5. E.A.	Ependymal Cyst	Moderate	Right dorsolateral frontal balloon shaped, with sub-orbital extension but not to ventricles	Left side clumsiness
6. B.H.	Internal Carotid Artery aneurysm	Moderate	Dorsolateral frontal, with some anterior parietal extension; Extension to lateral horn of right ventricle	Mild left arm drift
7. S.B.	Grade II-III astrocytoma	Moderate	Right frontal white matter just under cortex, anterior to premotor zone	None
8. J.S.	AVM bleed	Large	Right frontal, extending from pole posteriorly to parietal region subcortical extension to ventricles	None

Left Anterior				
1. K.R.	Grade II astrocytoma	Moderate	Posterior anterior, primarily medial but extending to orbital; some anterior temporal involvement	Mild upper extremity drift, right lower facial weakness, mild anterior aphasia at time of testing, mild word-finding deficit
2. P.G.	Infarct	Moderate	Broca's area, relatively limited	Transient right sided weakness; mild anterior aphasia - Little Broca. At time of testing mild word finding deficit; fluent, halting speech.
3. W.G.	MCA Infarct	Suggested small	Normal	Transient aphasia Right pronator drift Recovered at time of testing
Bifrontal				
1. L.B.	ACA aneurysm	None detected	Normal	Right mild transient hemiparesis; slurring of speech. Recovered at time of testing
2. P.C.	Metastatic Tumor	Moderate	Bifrontal parasagital area	Unconcern, apathy, loss of initiative
Right Posterior				
1. S.P.	Meningioma	Small	Right parietal, middle parasagital meningioma	Mild left foot drag
2. B.K.	MCA Infarct	Large	Temporoparietal region	None
3. K.A.	Infarct	Moderate	Right temporoparietal region	Left sided numbness, blurred vision. Recovered at time of testing
4. J.G.	Infarct	Small	Right temporoparietal region	Left sided numbness (face & hand)

Left Posterior				
1. D.F.	MCA Infarct	Moderate	Primarily affecting temporal distribution	Normal
2. T.B.	Meningioma	Moderate	Supra & Infratentorial mass, posterior fossa; dilated left occipital horn; left occipital craniotomy	Normal
3. E.A.	MCA Infarct	Small	Left parietal-temporal	Mild aphasia - Recovered at time of testing
4. F.D.	Intracerebral hematoma	Small	Left parietal-temporal	Mild aphasia - Recovered at time of testing
5. D.B.	Ependymal cyst		Left parietal with some anterior extension	Normal

Appendix 9A

Test scores of patients with Subcortical Lesions on Increasing Span Task

Subject	Verbal					
	a) 6		9		12	
	b) TT	c) %CJ	TT	%CJ	TT	%CJ
R.M.	67	100	93	100	489	88
J.T.	65	80	192	100	915	70
K.H.	88	100	203	83	545	0
M.W.	23	100	136	83	416	82
			Pictorial			
R.M.	89	100	180	83	514	82
J.T.	115	73	179	100	504	82
K.H.	74	67	247	79	326	70
M.W.	143	100	292	100	638	100

a) Number of units in sequence
b) Total time in seconds taken to complete three trials at each sequence length
c) Percent of correct junctures obtained over three trials of each sequence length

Appendix 9B

Test scores of patients with Subcortiecal Lesions

on Capture Error Task

	a) Correct				Incorrect				
S	b) TC	c) TT	d) CJ	e) %CS	TC	TT	CJ	%CS	f) CE
Verbal									
R.M.	12	12	5.0	100	9	17	5.0	100	0
J.T.	25	25	4.6	80	14	22	4.7	90	1
K.H.	24	27	3.9	60	31	35	3.7	60	3
M.W.	8	9	5.0	100	30	33	4.6	90	0
Pictorial									
R.M	199	284	4.5	83	212	526	3.8	67	1
J.T.	206	307	4.5	83	166	314	4.5	83	1
K.H.	138	180	3.5	50	126	210	3.3	33	1
M.W.	435	435	4.0	66	213	464	3.2	33	1

a) Validity of association
b) Average time associated units were kept together
c) Average time taken to complete sequences
d) Average number of correct junctures
e) Percent of correct sequences
f) Capture errors

Appendix 10

Script for Initial Contact with Control Subjects

We are presently carrying out a study investigating the effects of brain injury on the ability to put information in logical order. To do this, we have administered a series of question and answer tests to a number of people who have suffered strokes, or other neurological problems.

To complete our study we need to gather information from people who are in the general age range of our patients and have equivalent levels of education but who have no history of neurological problems.

The study consists of a 1 & 1/2 hour session, during which you will be asked to organize sets of cards, with words or pictures on them, into logical sequences.

Your cooperation will assist us in various ways. First, you will help advance basic science. Second, this knowledge will be useful to us in helping people who have experienced neurological problems. Although all information is confidential, the general data will be used for research and publication purposes.

Appendix 11

Stimuli for Verbal Subtest of Increasing Span Task

1. a) spoon bring me the
   b) (bring me the spoon)

2. sings girl well that
   (that girl sings well)

3. house they our bought
   (they bought our house)

4. is button jacket a missing my
   (my jacket is missing a button)

5. was our midnight dark at town
   (our town was dark at midnight)

6. sea she of pictures likes the
   (she likes pictures of the sea)

7. burning clouds the city black of smoke from rose
   (black clouds of smoke rose from the burning city)

8. trip some we for made home long the food
   (we made some food for the long trip home)

9. a we ride into him to offered town give
   (we offered to give him a ride into town)

10. ahead the not face are hardships that we to lie afraid many
    (we are not afraid to face the many hardships that lie ahead)

11. many abroad they from were return the spent pleased home to months
    (they were pleased to return home from the many months spent abroad)

12. danger we than that expected greater to the was admit had he
    (we had to admit that the danger was greater than he had expected)

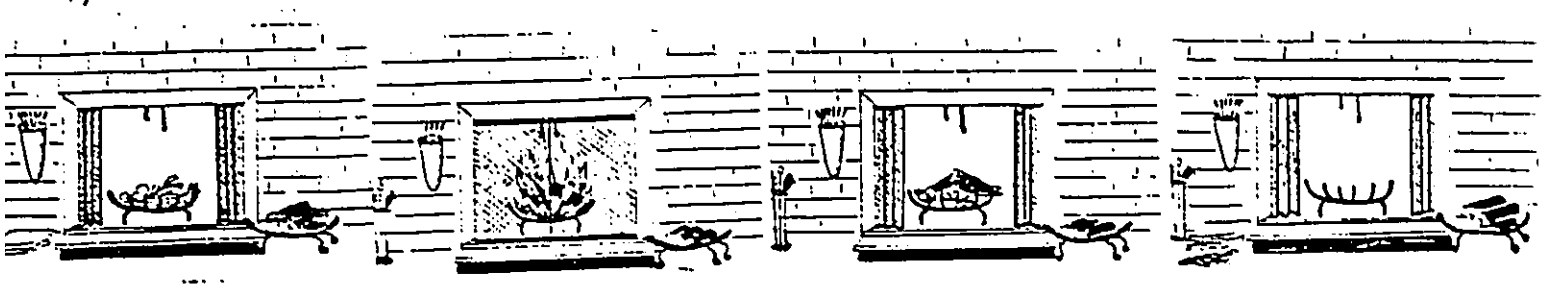
a) Order of presentation
b) Correct solution

Appendix 12

Pictorial Stimuli for Increasing Span Task

Stimuli are displayed in order of presentation. Legend below indicates the correct order of solution.

1)



B D C A

A B C D

Appendix 12

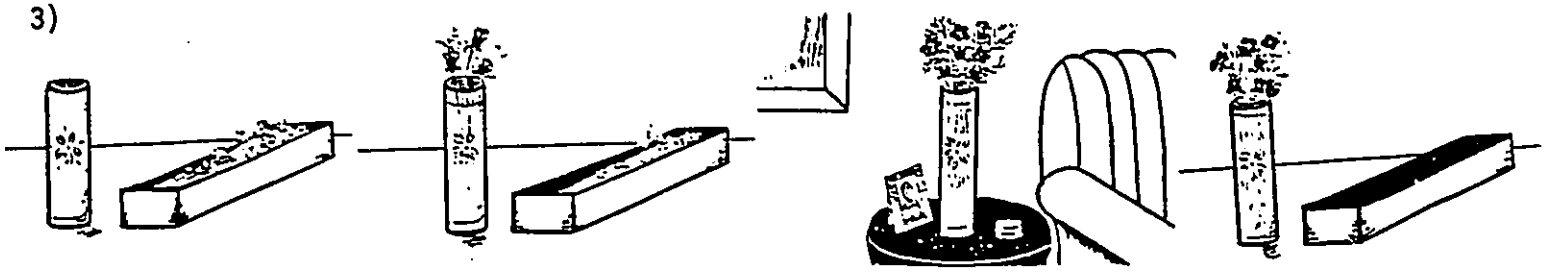
2)

D C A B

A B C D

Appendix 12

3)

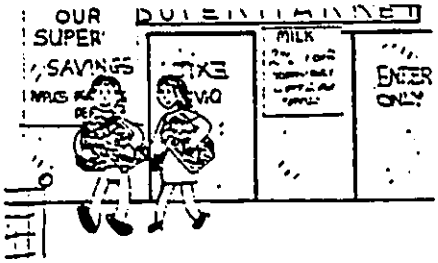


A B C D

Appendix 12

4)

C



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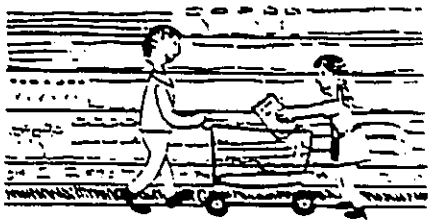

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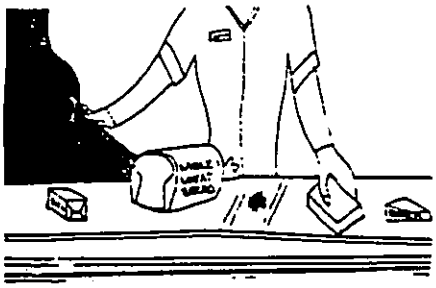

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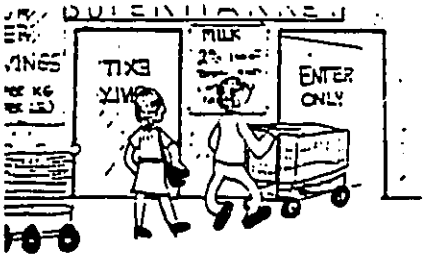

A

E

A B C D E F

Appendix 12

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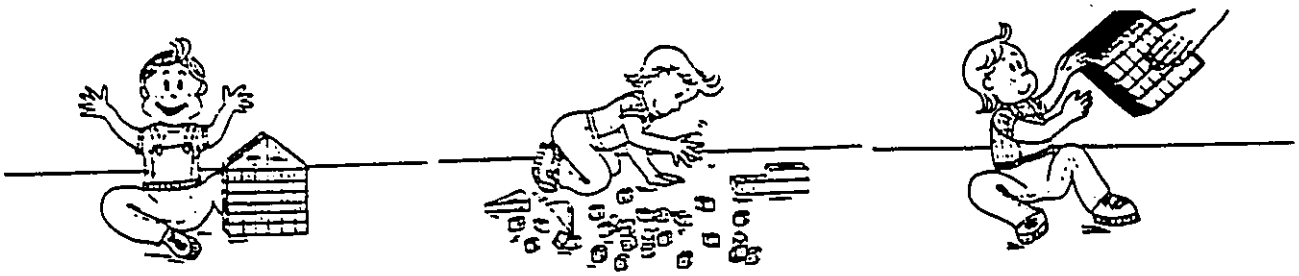
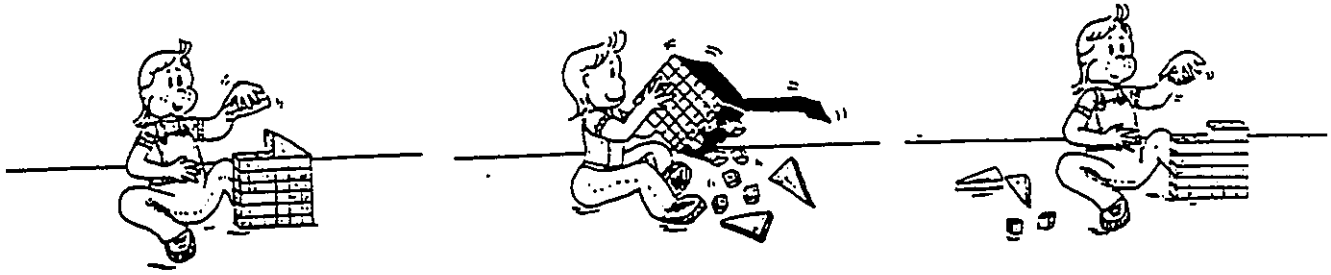


F C A



E B D

A B C D E F

Appendix 12

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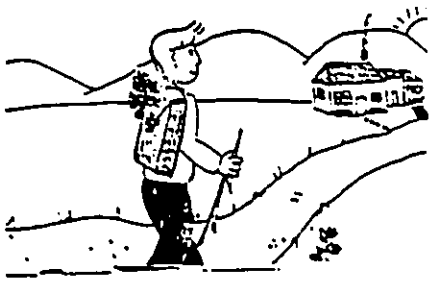

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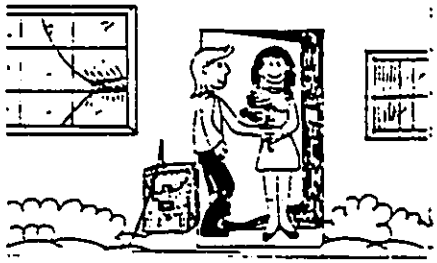

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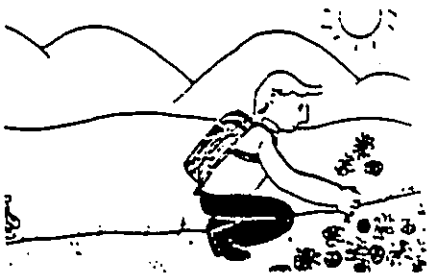

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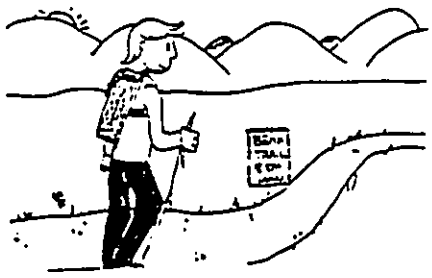

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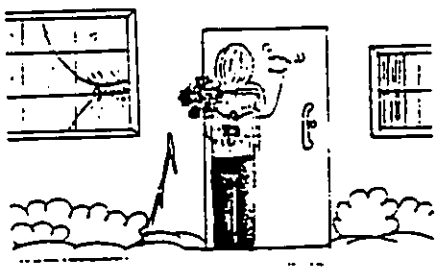

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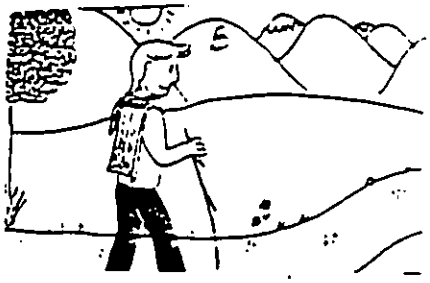

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A B C D E F

Appendix 12

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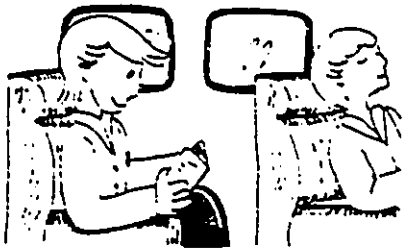

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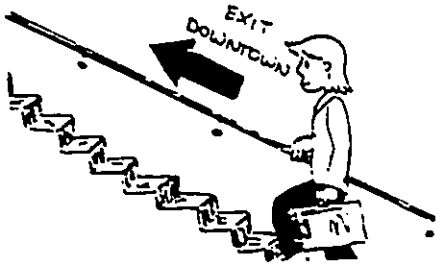

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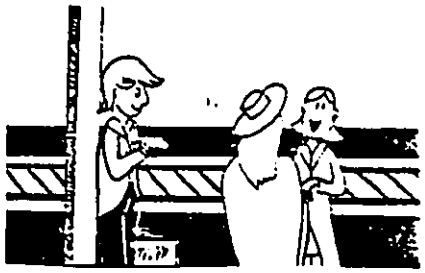

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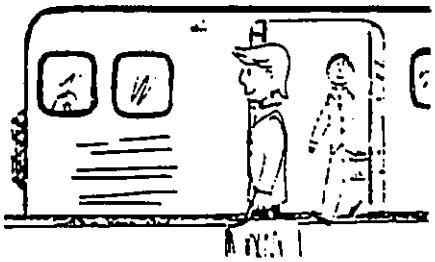

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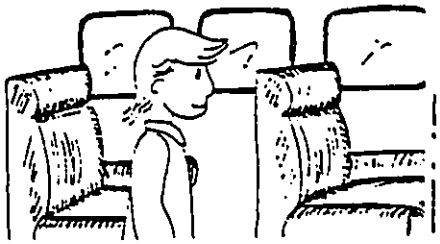

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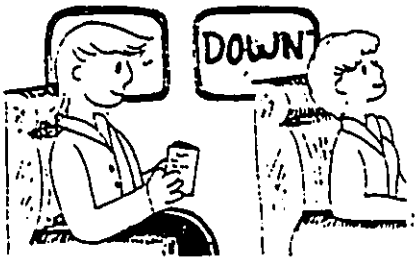

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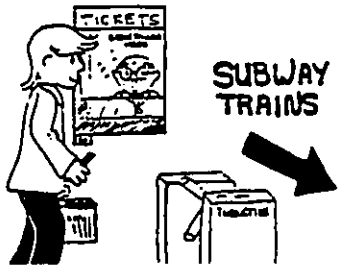

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A B C D E F G H I

Appendix 12

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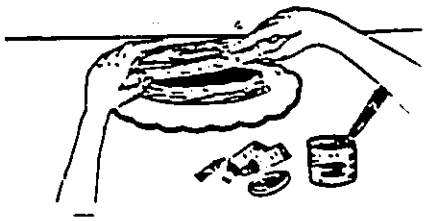

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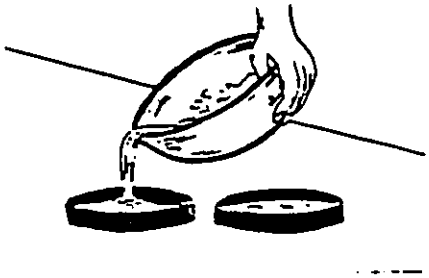

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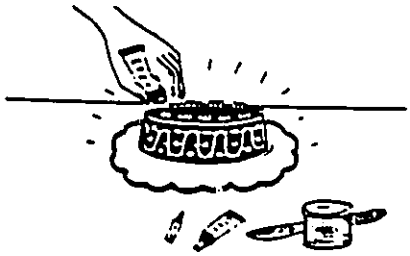

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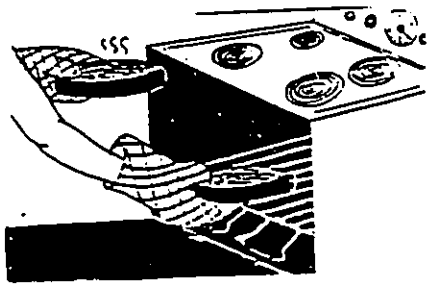

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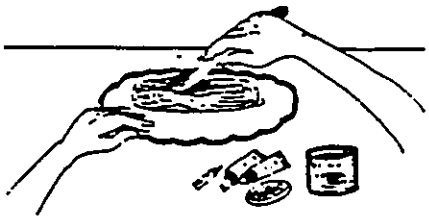

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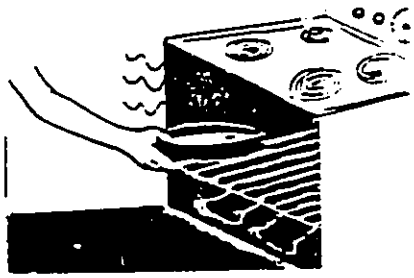

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A B C D E F G H I

Appendix 12

9)

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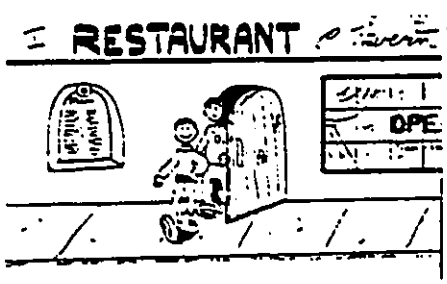

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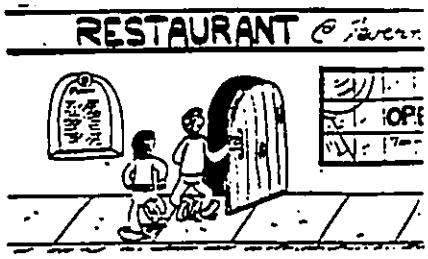

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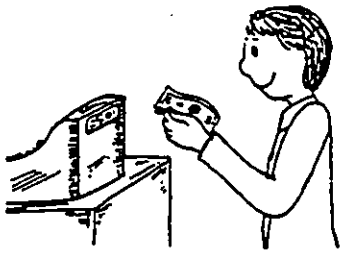

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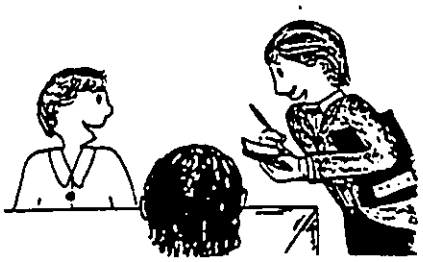

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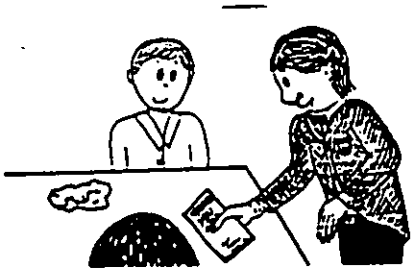

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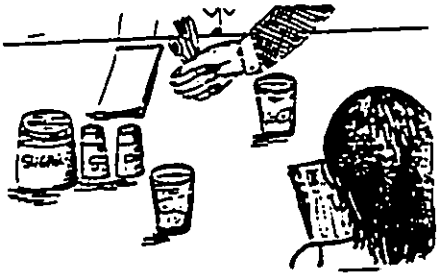

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A B C D E F G H I

Appendix 12

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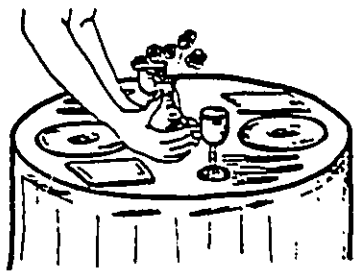

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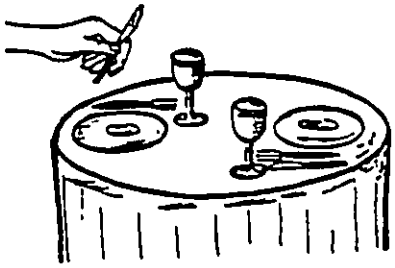

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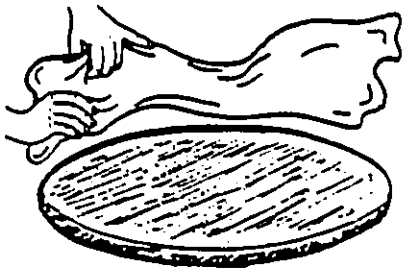

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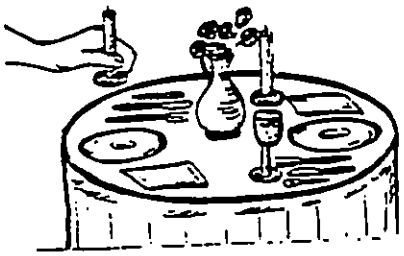

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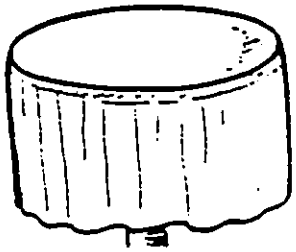

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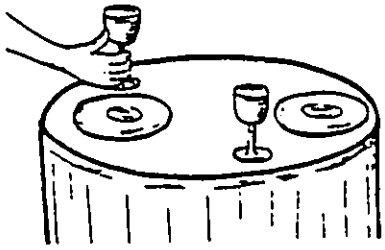

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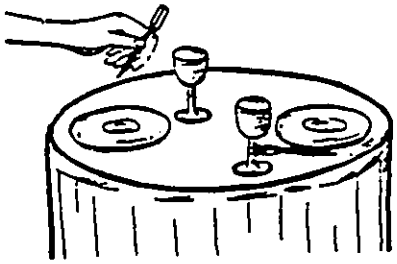

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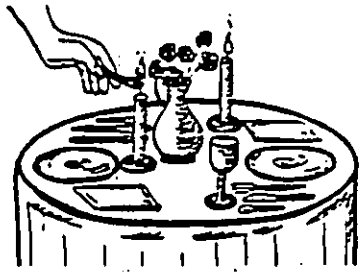

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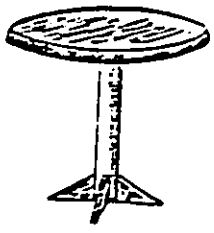

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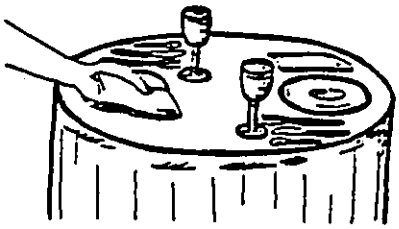

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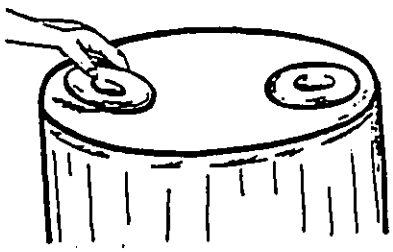

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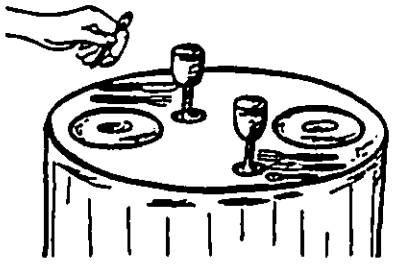

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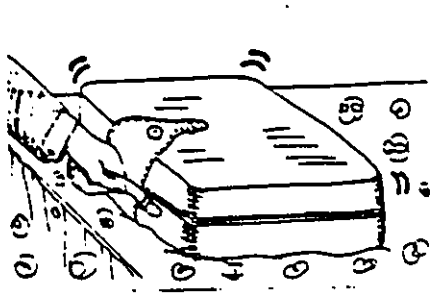
A B C D E F G H I J K L

Appendix 12

11)



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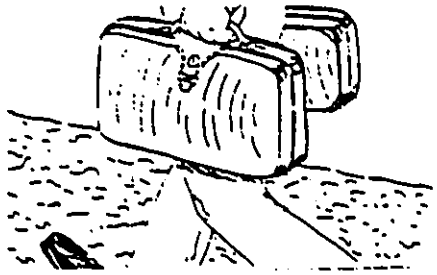

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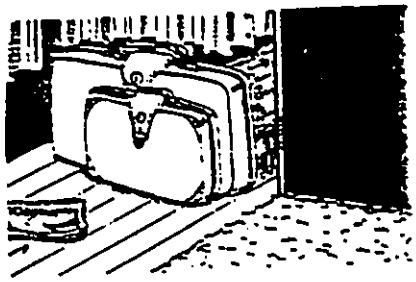

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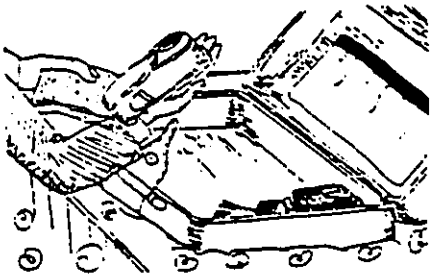

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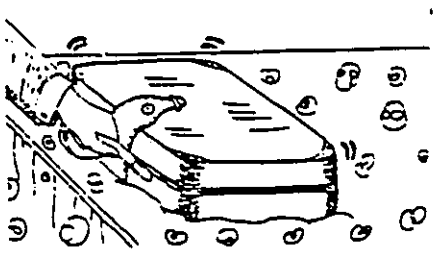

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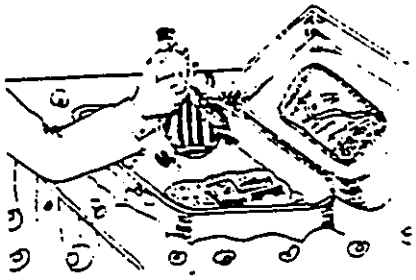

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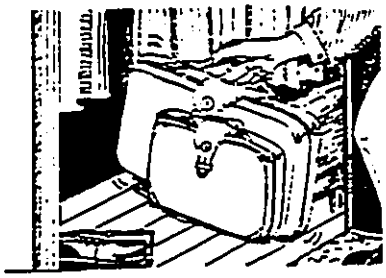

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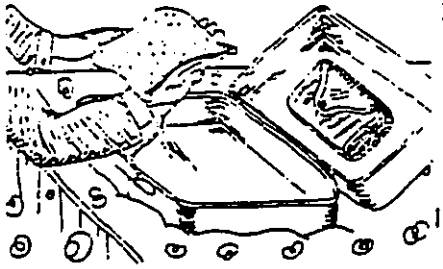

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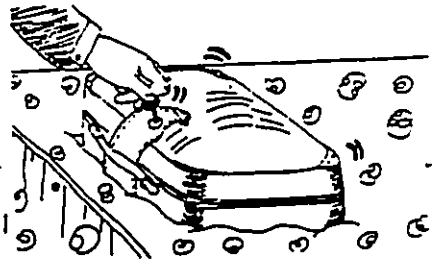

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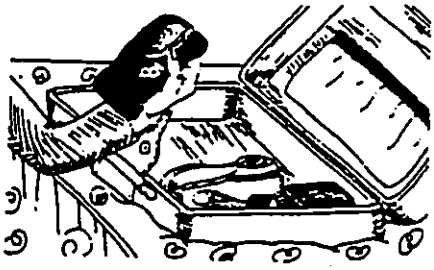

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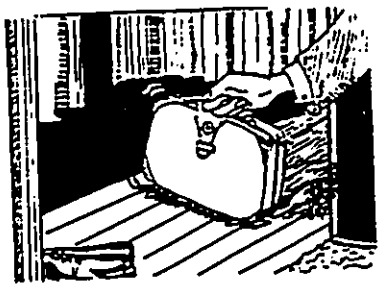

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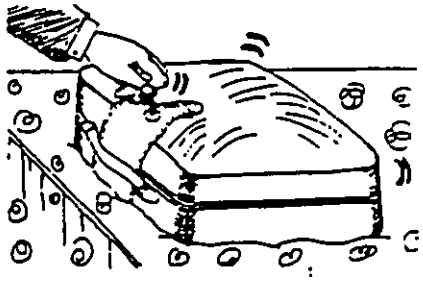

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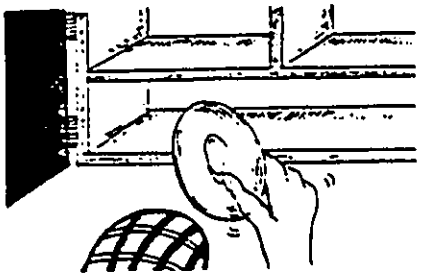
A B C D E F G H I J K L

Appendix 12

12)



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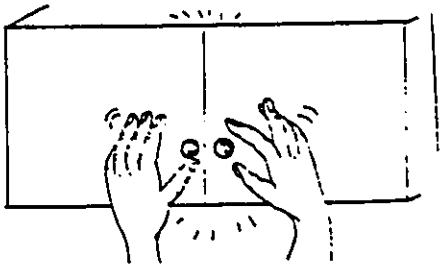

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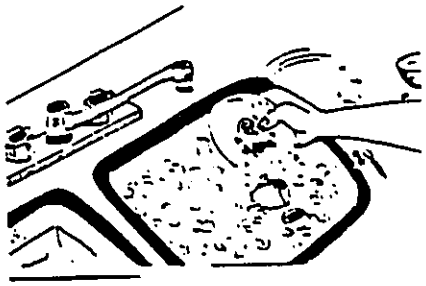

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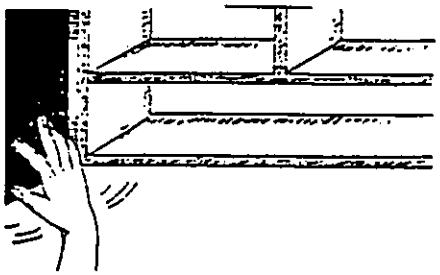

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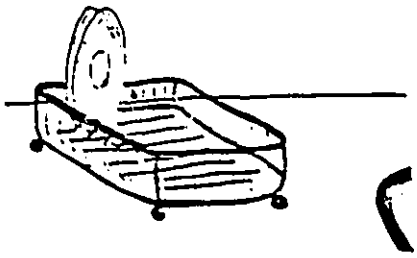

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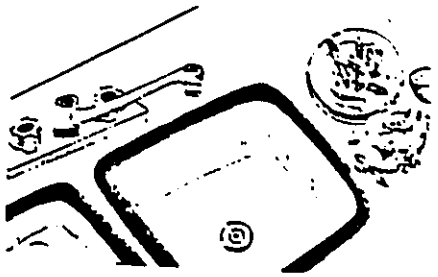

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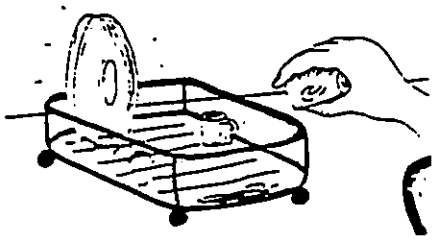

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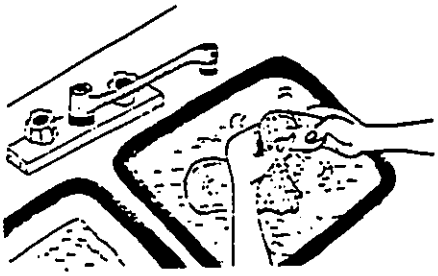

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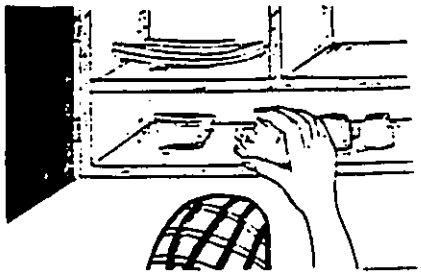

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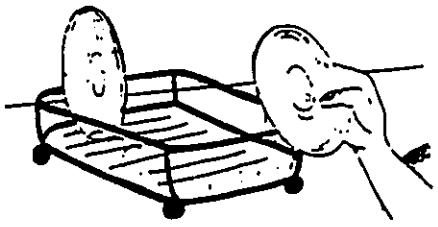

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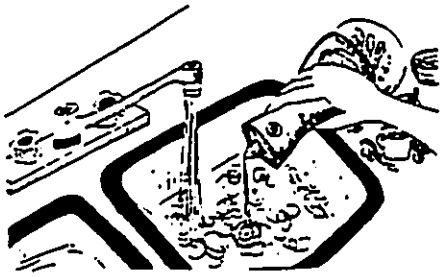

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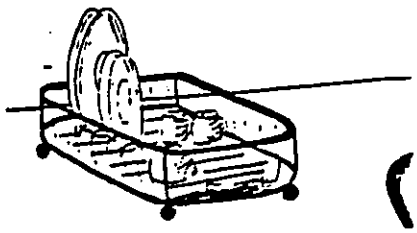


H

A B C D E F G H I J K L

Appendix 13

Stimuli for Verbal Subtest of Capture Error Task

1. a) sped accident the to fire engines
   b) (fire engines sped to the accident)

2. open always front door was their
   (their front door was always open)

3. in a winter coat he wears
   (he wears a coat in winter)

4. city heavy fog the covered entire
   (heavy fog covered the entire city)

5. coffee try this brand new of
   (try this new brand of coffee)

6. lunch ate they for club sandwiches
   (they ate club sandwiches for lunch)

7. hung clothes line the on she
   (she hung clothes on the line)

8. with my fur coat is lined
   (my coat is lined with fur)

9. enjoyed most sleigh ride guests the
   (most guests enjoyed the sleigh ride)

10. with he filled wine glass his
    (he filled his glass with wine)

11. sky the lit full moon a
    (a full moon lit the sky)

12. book worms about read a they
    (they read a book about worms)

13. red roses home grows at she
    (she grows red roses at home)

14. was of coffee cup the full
    (the cup was full of coffee)

15. crowded always dining room is that
    (that dining room is always crowded)

16. empty the are hospital beds never
    (hospital beds are never empty)

17. honey bees of the made lots
(the bees made lots of honey)

18. they for at twelve lunch break
(they break for lunch at twelve)

19. cheese with delicious is apple pie
(apple pie is delicious with cheese)

20. the first aid were to they
(they were the first to aid)

a) Order of presentation
b) Correct solution

Appendix 14

Questionnaire for Frequency of Word Pairs in Capture Error Task

Rate the following word pairs in terms of how strongly they are associated - how frequently you think they may occur together.

Word Pairs			
fire engines	____	wine glass	____
fire accident	____	filled glass	____
engines sped	____	wine filled	____
front door	____	full moon	____
open door	____	moon lit	____
their door	____	full sky	____
wears coat	____	read book	____
winter coat	____	read about	____
in winter	____	book worms	____
entire city	____	grows roses	____
heavy fog	____	red roses	____
city fog	____	red house	____
new coffee	____	full cup	____
brand new	____	coffee cup	____
new brand	____	cup full	____
ate lunch	____	dining room	____
ate sandwiches	____	full room	____
club sandwiches	____	crowded room	____
line hung	____	hospital beds	____
hung clothes	____	empty beds	____
clothes line	____	empty hospital	____
lined coat	____	honey bees	____
fur coat	____	bees made	____
fur lined	____	made honey	____
sleigh ride	____	lunch break	____
guests enjoyed	____	for lunch	____
guests ride	____	twelve lunch	____
delicious cheese	____	first aid	____
delicious pie	____	they aid	____
apple pie	____	were first	____

Rating Scale

1 - Don't belong together

2 - Probably don't belong together

3 - May belong together

4 - Strongly belong together

5 - Very strongly belong together

Appendix 15

Frequency Distribution of Word Pairs

in Capture Error Task

Results of Normative Questionnaire

Rating Scale	a) 1-2	b) 3	c) 4-5
Word Pairs			
fire engines	0	3	62
fire accident	22	34	9
engines sped	45	16	4
front door	0	0	65
open door	0	10	55
their door	16	37	12
wears coat	34	25	6
winter coat	0	3	62
in winter	8	23	34
entire city	5	24	36
heavy fog	1	6	58
city fog	31	25	9
new coffee	42	19	4
brand new	0	4	61
new brand	8	28	29
ate lunch	4	13	48
ate sandwiches	6	27	32
club sandwiches	0	10	55
line hung	10	34	21
hung clothes	10	34	21
clothes line	0	0	65
lined coat	4	25	36
fur coat	0	0	65
fur lined	3	22	40
sleigh ride	1	0	64
guests enjoyed	13	37	15
guests ride	48	15	2
wine glasses	0	1	64
filled glass	12	25	28
wine filled	35	18	12
full moon	0	0	65
moon lit	3	15	47
full sky	36	22	7
read book	16	22	27
read about	11	17	37
book worms	3	9	53
grows roses	16	28	21

Rating Scale	1-2	3	4-5
Word Pairs			
red roses	0	0	65
red house	10	33	22
full cup	1	16	48
coffee cup	2	2	61
cup full	15	20	30
dining room	0	0	65
full room	9	38	18
crowded room	0	16	49
hospital beds	0	4	61
empty beds	0	20	45
empty hospital	37	16	12
honey bees	0	4	61
bees made	34	26	5
made honey	24	31	10
lunch break	0	6	59
for lunch	6	27	32
twelve lunch	52	9	4
apple pie	0	0	65
delicious cheese	4	24	37
delicious pie	3	10	52
first aid	0	0	65
they aid	46	19	0
were first	29	27	9

a) 1-2 : Don't belong together; or Probably don't belong together

b) 3 : May belong together

c) 4-5 : Strongly belong together; or Very strongly belong together

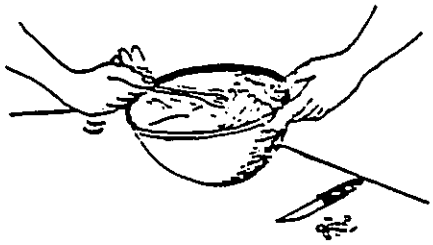
d) Underlined pairs are the valid and invalid associated pairs

Appendix 16

Pictorial Stimuli for Capture Error Task

Stimuli are displayed in order of presentation. Legend below indicates the correct order of solution.

1)



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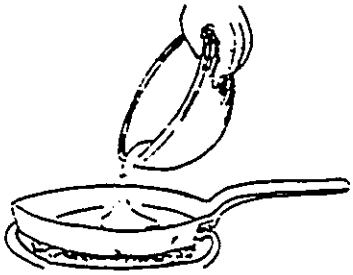

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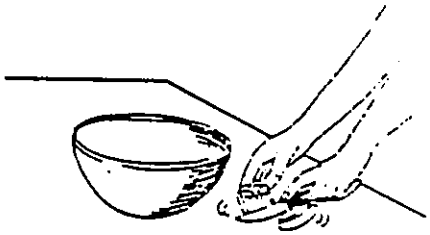

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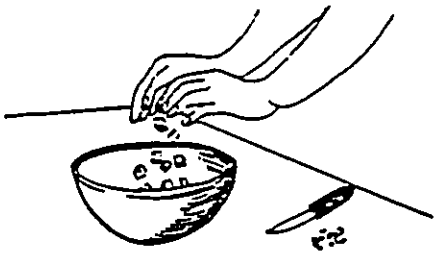

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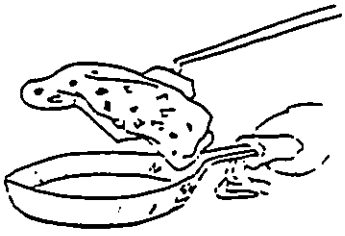

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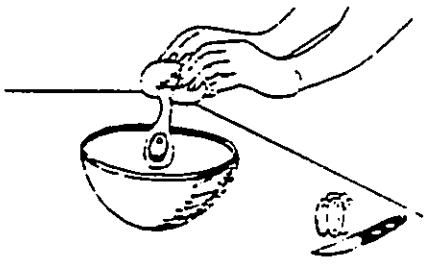
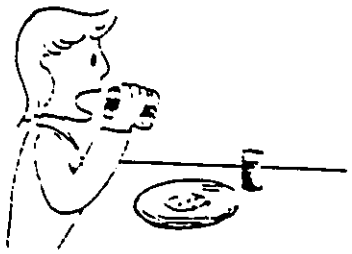


A

A B C D E F

Appendix 16

2)



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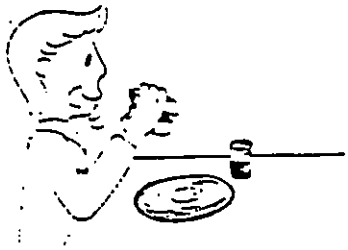

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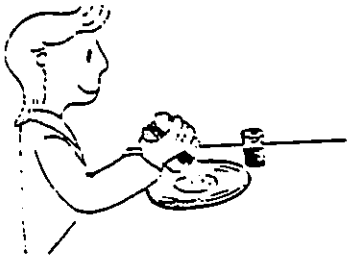

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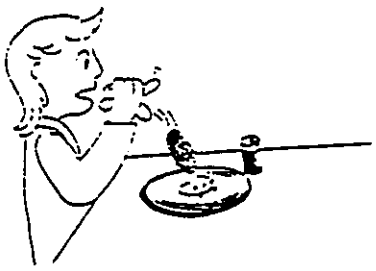

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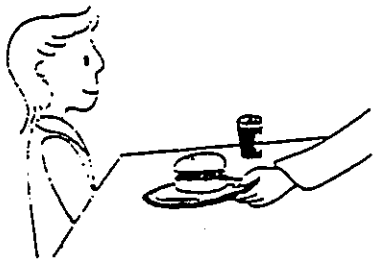

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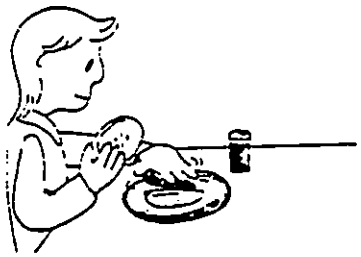
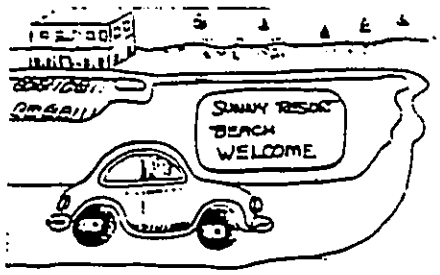


D

A B C D E F

Appendix 16

3)



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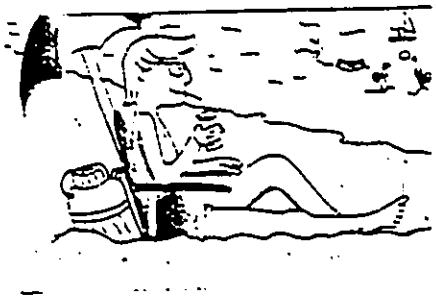

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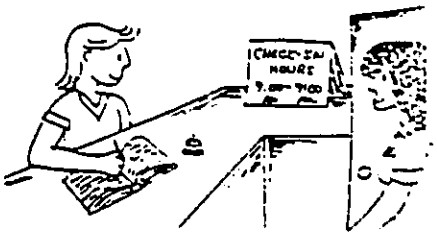

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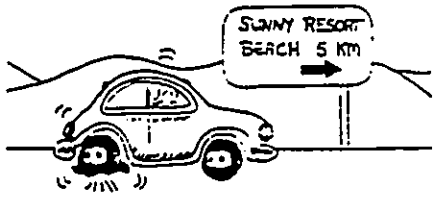

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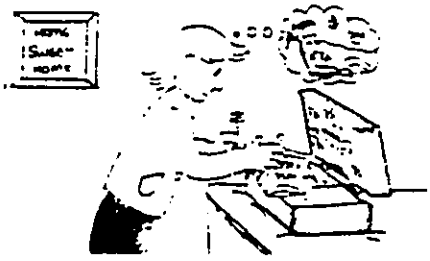
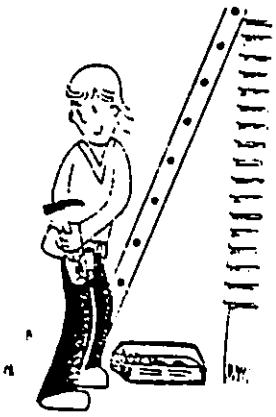


A

A B C D E F

Appendix 16

4)



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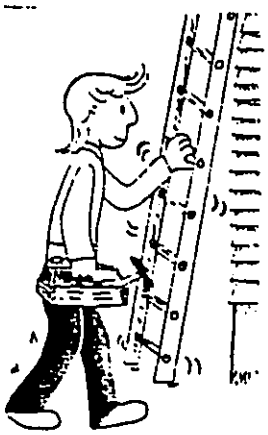

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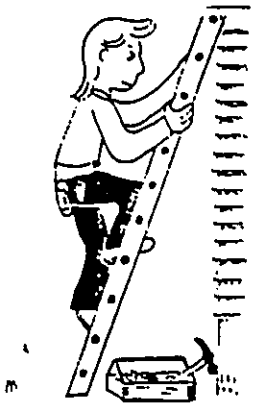

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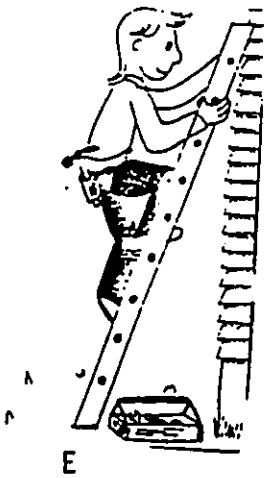
F *



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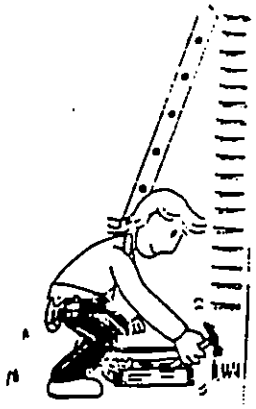
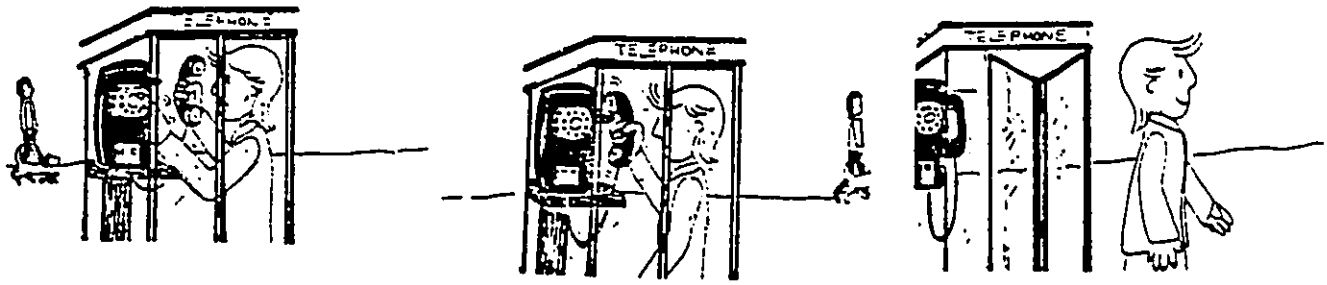


C

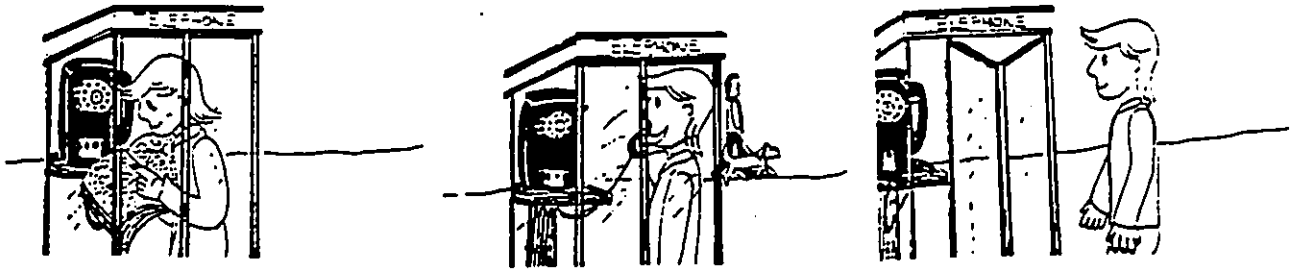
A B C D E F

Appendix 16

5)



C E * F *

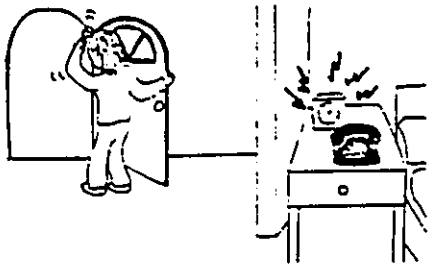


B D A

A B C D E F

Appendix 16

6)



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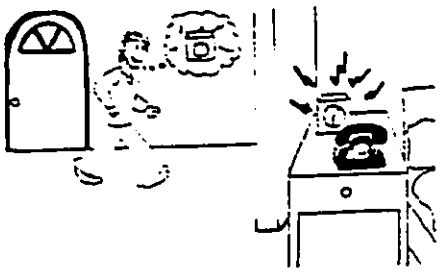

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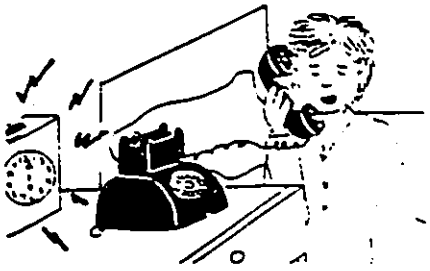

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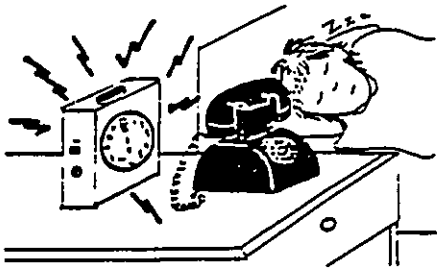

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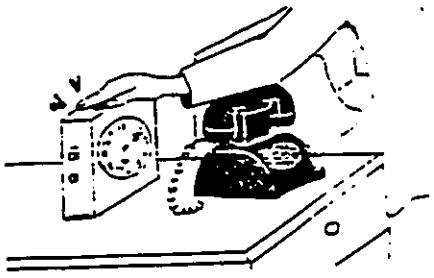

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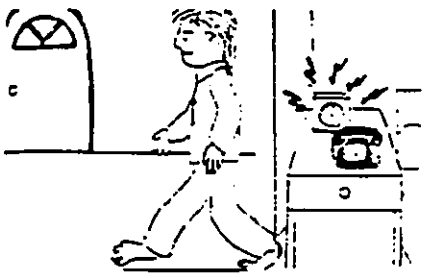
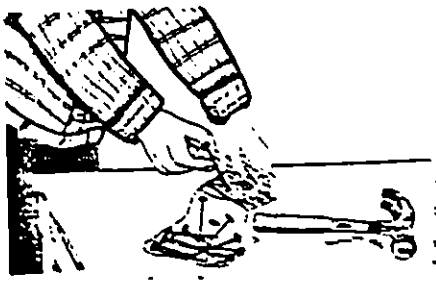


C

A B C D E F

Appendix 16

7)



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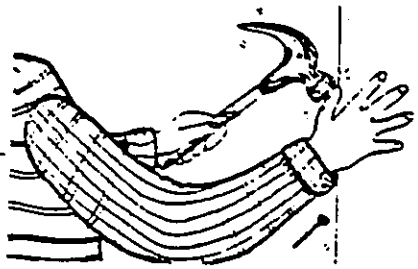

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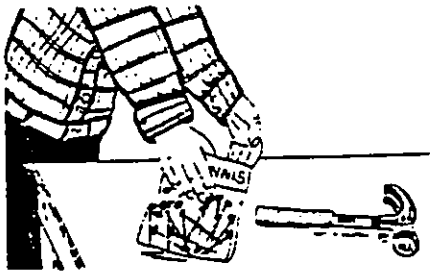

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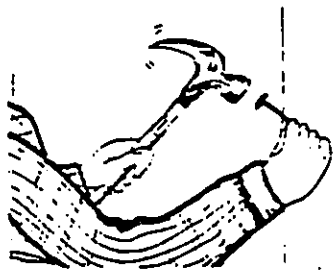

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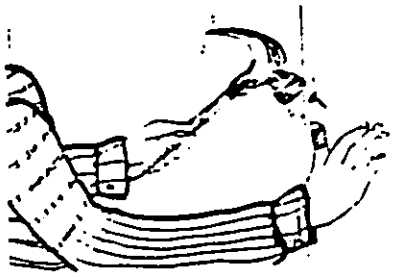

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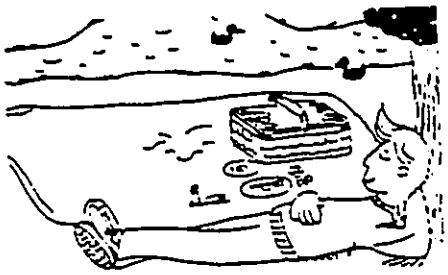
A B C D E F

Appendix 16

8)



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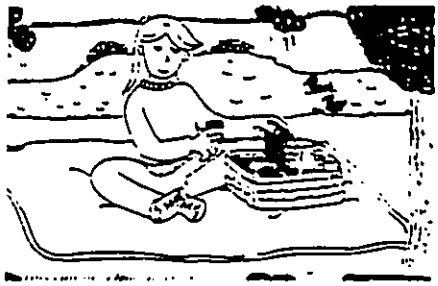

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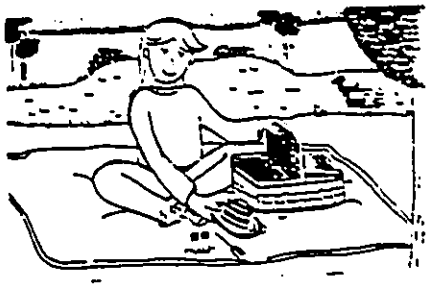

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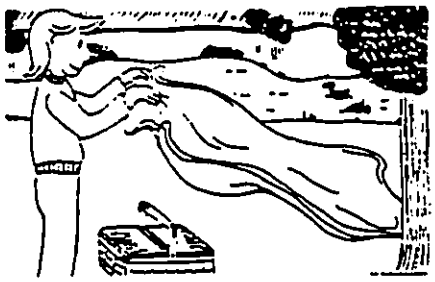

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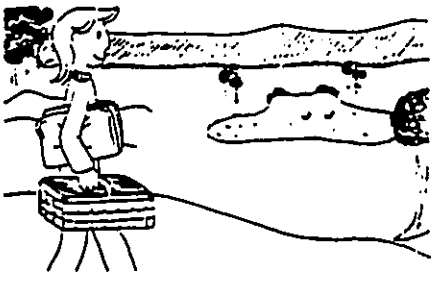


A

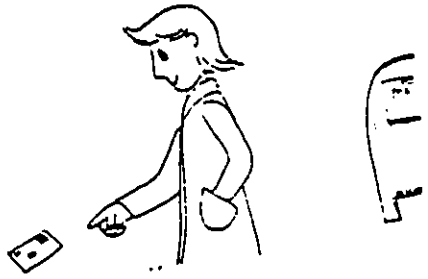
A B C D E F

Appendix 16

9)

C *

F *



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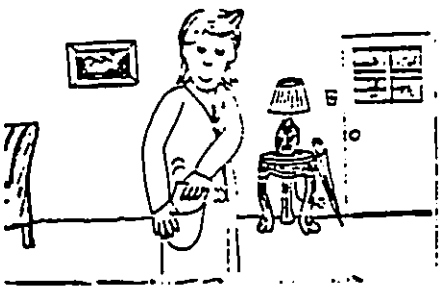

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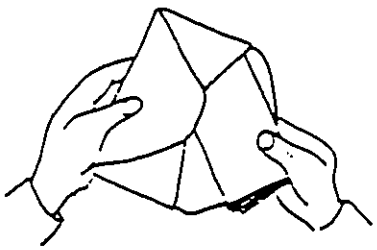

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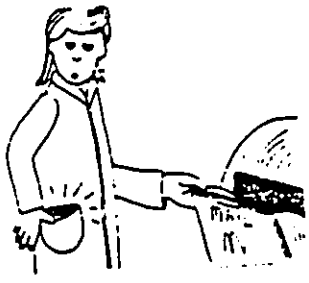
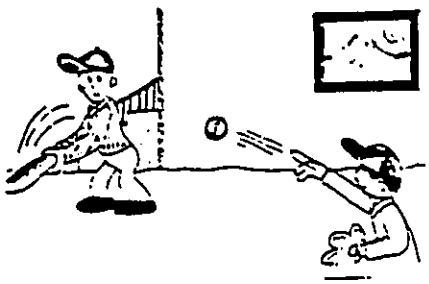


D

A B C D E F

Appendix 16

10)



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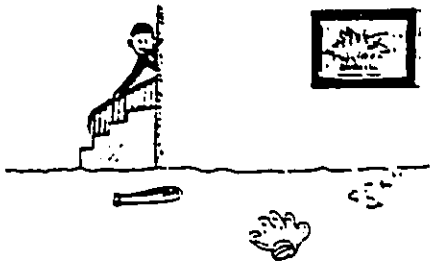

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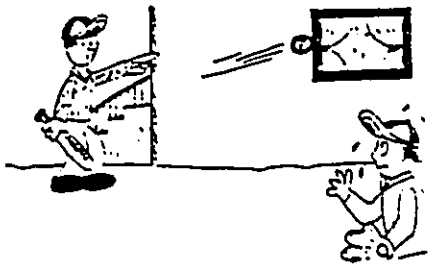

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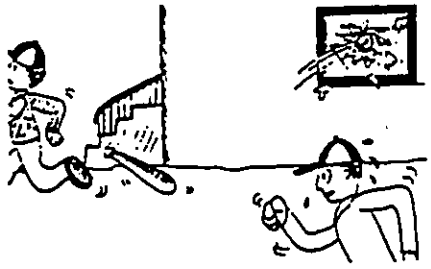

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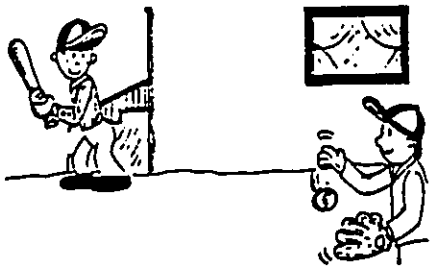

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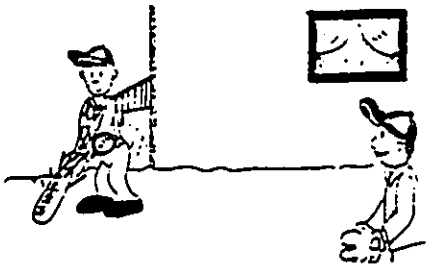
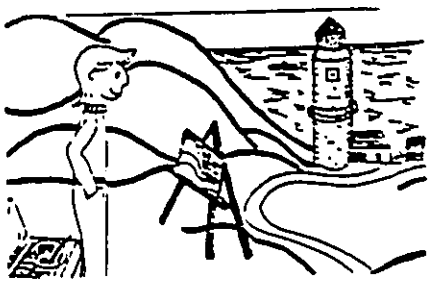


C

A B C D E F

Appendix 16

11)



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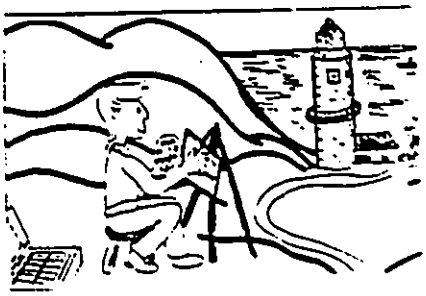

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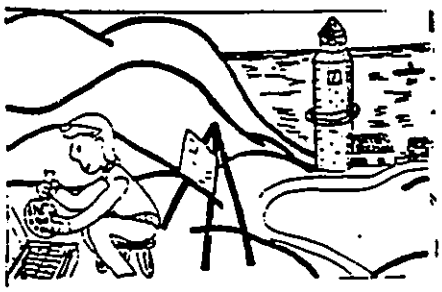

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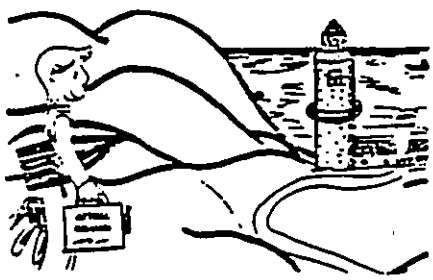

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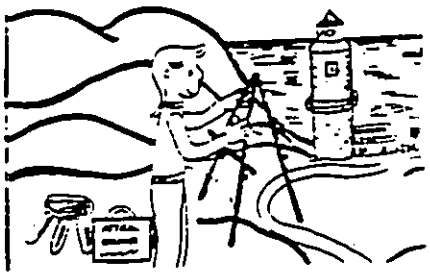


B*

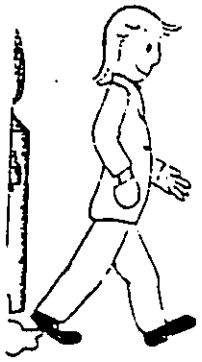
A B C D E F

Appendix 16

12)

C

D



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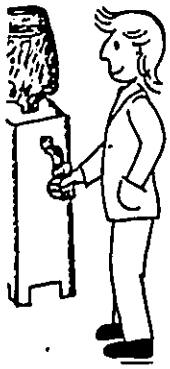

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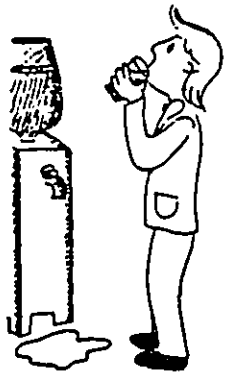

E*

A

A B C D E F

Appendix 17

Sample Sheet for Verbal Increasing Span

1. spoon bring me the

   bring me the spoon — TT 6 (a) / CJ 3 (b)

2. signs girl well that

   that girl sings well — TT 6 / CJ 3

3. house they our bought

   they bought our house — TT 8 / CJ 3

---

4. is button jacket a missing my

   my jacket is missing a button — TT 10 / CJ 5

5. was our midnight dark at town

   our town was dark at midnight — TT 55 / CJ 5

6. sea she of pictures likes the

   she likes pictures of the sea — TT 26 / CJ 5

---

7. burning clouds the city black of smoke from rose

   black clouds of smoke rose from the burning city — TT 225 / CJ 8

8. trip some we for made home long the food

   the long trip we made home for some food — TT 222 / CJ 5

9. A we ride into him to offered
town give

we made some food for the long trip home — TT 38, CJ 8

---

10. Ahead the not face are hardships
that we to lie afraid

the many hardships we are afraid to face lie ahead — TT 330, CJ 6

11. Many abroad they from were return
the spent pleased home to months

they were many pleased to return home from the months spent abroad — TT 193, CJ 8

12. danger we than that expected greater
to the was admit had

he admit that we had to expected greater danger — TT 210, CJ 3

Sample Calculations for the Different Sequence Lengths

Total Time (4)= 6+6+8 = 20 sec

% Correct Junctures (4) = (3+3+3)/9 X 100 = 100%

Total Time (6) = 10+55+26 = 91 sec

% Correct Junctures (6) = (5+5+5)/15 X 100 = 100 %

Total Time (9) = 225+222+38=485

% Correct Junctures (9) = (8+5+8)/24 X 100 = 87.5%

Total Time (12)=330+193+210=733

% Correct Junctures (12) = (6+8+3)/33 X100 = 51.5%

(a) TT = Total time to complete sequences
(b) CJ = Number of correct junctures

Appendix 18

Sample Score Sheet for Verbal Capture Task

		Correct		Incorrect	
sped accident the to fire engines	TC	3	(a)		
	TT	58	(b)		
the fire engines sped to accident	CJ	58	(c)		
open always front door was their	TC	5			
	TT	30			
their front door was always open	CJ	30			
in a winter coat he wears	TC			1	
	TT			25	
he wears in a winter coat (CE)	CJ			30	
city heavy fog the covered entire	TC	5			
	TT	22			
heavy fog covered the entire city	CJ	22			
coffee try this brand new of	TC			5	
	TT			50	
try this new brand of coffee	CJ			55	
lunch ate they for club sandwiches	TC	5			
	TT	19			
they ate club sandwiches for lunch	CJ	19			
hung clothes line the on she	TC			5	
	TT			12	
she hung clothes on the line	CJ			18	
with my fur coat is lined	TC			5	
	TT			30	
my coat is lined with fur	CJ			45	
enjoyed most sleigh ride guests the	TC	5			
	TT	30			
most guests enjoyed the sleigh ride	CJ	30			

with he filled wine glass his
he filled his glass with wine

TC 5
TT 13
CJ 20

sky the lit full moon a
the full moon lit the sky

TC 5
TT 68
CJ 68

book worms about read a they
they read about a book worms (CE)

TC 2
TT 270
CJ 270

red roses home grows at she
she grows red roses at home

TC 5
TT 17
CJ 17

was of coffee cup the full
the cup of coffee was full

TC 5
TT 9
CJ 17

crowded always dining room is that
that dining room is always crowed

TC 5
TT 26
CJ 26

empty the are hospital beds never
the hospital beds are never empty

TC 5
TT 23
CJ 23

honey bees of the made lots
the bees made lots of honey

TC 5
TT 25
CJ 44

they for at twelve lunch break
they break for lunch at twelve

TC 5
TT 14
CJ 21

cheese with delicious is apple pie
apple pie is delicious with cheese

TC 5
TT 18
CJ 18

the first aid were to they

TC 2
TT 120

they were to the first aid (CE) CJ 120

Sample Calculations

a) Correct Sequences = 1,2,4,6,9,11,13,15,16,19

Average Time = (58+30+22+19+30+68+17+26+23+18)/10
= 311/10
= 31.1

Average Time of Capture
=(58+30+22+19+30+68+17+26+23+18)/10
= 311/10
= 31.1

Number Correct Junctures = (3+5+5+5+5+5+5+5+5+5)/10 = 4.8

Percent Correct Sequences = 9/10 X 100 = 90%

b) Incorrect Sequences = 3,5,7,8,10,12,14,17,18,20

Average Time = (30+55+18+45+20+270+17+44+21+120)/10
= 640/10
= 64

Average Time of Capture
= (25+50+12+30+13+270+9+25+14+120)/10
= 568/10
= 56.8

Number Correct Junctures = (1+5+5+5+5+2+5+5+5+2)/10
= 40/10
= 4

Percent Correct Sequences = 7/10 X 100 = 70

Capture Error = 3

(a) TC = Average time associated units were kept together
(b) TT = Average number of correct junctures
(c) CJ = Average number of correct junctures