CHAPTER 1

INTRODUCTION

> *Music is a fertile ground for the development of thought in the cognitive sciences, but why would a scientist of the mind dare attempt an analysis of the nature of human musical experience? Can there be any realm of collective human production and response more obscure, mysterious and, finally, so absolutely personal and individual? At the same time, can any human science ignore one of the species' most unique capacities?* (McAdams, 1987: 1)

The aim of this program of research was to investigate individual differences in the information processing requirements for the perception of pitch fluctuations in music. The perception of music in general was conceptualised as a multi-stage information processing task. Three psychometric studies were undertaken: two with large samples of upper primary school children, one with a small sample of musically talented children of a similar age. Individual differences in information processing abilities were determined psychometrically by batteries constructed from an operationalisation of the neuropsychological model of Alexander Luria (1966a, 1966b, 1973, 1975, 1982). The model proposes three independent dimensions of information processing: simultaneous, successive and executive synthesis. It was hypothesised that these three dimensions are employed in the processing of musical information. It was also hypothesised that the information in musical stimuli is cognitively constructed into musical elements through autocorrelational processes, and that individual differences in music perception can be explained, in part, as differences in sensitivity to the autocorrelation structure of tone sequences. The experimental results supported these hypotheses.

1.1 Rationale for the research program

Umemoto (1990) argues that music perception "is now one of the most promising subjects for scientific research" (p. 115), but that "more studies on neuropsychological, developmental, educational and ethnological factors will be required in the future" (p. 119). McAdams suggests that the main thrust of music cognition has been to inform more general aspects of cognitive functioning. "Since music is uniquely human there is a logical connection between the structure of music and that of the mind which produces and perceives it" (p. 2). Or as Thomas puts it:

"Music is the effort we make to explain to ourselves how our brains work" (Krumhansl, 1992: 198). Certainly music is an ubiquitous art form; all human cultures have music. This alone suggests that music cognition is an important area for study.

McAdams (1987) lists four particular concerns for investigation:

- *the perception of musical qualities of sound;*
- *the cognitive processes of organisation, representation and storage of music;*
- *the nature of inborn and learned musical aptitudes; and,*
- *the brain functions underlying musical processes* (p. 9).

However, the research endeavour to date has yet to bridge

> *a large gap [which] still exists between what musicians recount of their experience, what psychoacousticians say about human auditory discriminatory powers, and what perceptual psychologists say about limits of human auditory organisation* (p. 10).

In an endeavour to reduce such gaps in knowledge, this research program attempted to avoid the circularity of employing a cognitive model based only on previous music aptitude measures (Karma, 1985). West, Cross and Howell (1987) propose "more serious consideration of process models of music perception [so] that ... we can determine what is actually going on in the brain when we listen to music" (p. 17). Here, a validated and reliable model of general cognitive performance, the Luria model, was used, and its explanatory powers in the music domain were evaluated.

There are several stages at which music can be regarded as an information processing event. First a composer creates a piece of music as a mental acoustical image. This image is then transformed into symbolic representation as a score. At some later time a performer reads and interprets the score presumably utilising a set of well learned mental schema. Here the processed information is used to coordinate fine motor responses of muscles in fingers, lips, vocal folds etc. An improvising performer combines this last stage with the first. Now music perception for listeners (who include the performer) begins. The listener perceives an acoustic surface which is interrogated by the auditory sensori system and converted into neuronal impulses for cortical processing. The efferent outcomes range from internalised emotional and aesthetic responses to motor responses such as dancing.

As with any communication, information can be transformed, e.g., apparently lost or misunderstood, at any stage. What conserves musical sense from composer through performer to listener is musical structure or form. Thus musical structure can be defined from both the creative and perceptive points of view. This mirrors the polarity in the perceptual psychology literature between phenomenology, attributed to Hering and Mach, and mentalism, such as proposed by Mill and Helmholtz (Hochberg, 1984). Through her theory of perceptual learning, E. J. Gibson attempts a reconciliation of these two positions in the case of music through the necessity of resolving informational redundancy. The ability to perceive musical structure, then, can be regarded as an individual difference variable. That is, the gap between what is intended or composed and what is heard or perceived will be a function of individual differences among listeners. The multi-dimensional nature of musical structure implies a wide range for individual differences:

- in performance, through expression, performance errors, and memory;
- in perception, through the relative salience of music events and ratings of overall quality;
- in learning, through levels of competence and differences in enculturation; and,
- in response, through interpretation and emotional reactions.

To investigate individual differences in such cognition a model was required which could operationalise information processing as it progresses from the specific to the general across independent modes of information presentation, as well as account for the role of attentional processes in the production of efferent behaviours. The Luria neuropsychological model as operationalised over two decades of research, mainly in Australia and Canada, met these criteria (e.g., Das, 1973; Fitzgerald, 1978, 1990; Geake, 1991; Green, 1977; Hunt, Randhawa & Fitzgerald, 1976; Klich, 1983; Leasak, Hunt & Randhawa, 1982; Ransley, 1981; Golden, Purisch & Hammeke, 1985; Naglieri, Das & Jarman, 1990). By employing such a model this research program departed from much of the previous endeavour in music cognition. Rather than ask how a particular measure of music perception might imply a generic cognitive music structure or organisation, this research focussed on variance in musical perception. Since the Luria model had not been used previously in music cognition, it first needed to be established that the dimensions of the model did relate to measures of musical perceptual ability. That done, the model was employed to investigate differences in cognitive abilities between subject groups such as musically gifted and musically normal children.

In the music cognition literature there are usages of terminology which suggest that the operationalised Luria model may be apposite. For example, the model conceptualises two independent dimensions for encoding information: simultaneous and successive synthesis. Successive synthesis involves the ordering or chaining of information for sequential processing or recall; simultaneous synthesis involves the quasi-spatial organisation of information. Identical terminology is used for the grouping of concurrent and sequential acoustic elements: "successive" for rhythmic and melodic, and "simultaneous" for chordal and timbrel groupings (e.g., Bregman, 1994). Furthermore, the Luria model is based on a hierarchical cerebral organisation which bridges higher and lower levels of cognitive processing, and gives due importance to the role of memory. Similar models are employed in music cognition.

> *Our limits of appreciation of musical form are thus determined by the limits of what we can represent in memory. The extent to which we can follow a musical discourse depends on our having previously acquired the necessary grammatical structures or on our being able to infer/reconstruct these structures from the musical material itself. This is the process of accumulating and experiencing musical form* (McAdams, 1987:56).

In the Luria model, the two coding dimensions interact in a cyclic hierarchy to chunk information for memory and higher order processing (Das, Naglieri & Kirby, 1994). Thus individual differences in responses to music training can be accounted for by abilities in coding musical information, i.e., by individual differences in music perception. Furthermore, the Luria model accounts for cognitive development in children as the maturation of simultaneous and executive syntheses through experience, consistent with evidence for children's musical development (Gordon, 1979).

The subject of individual musical abilities is current, as a recent issue of the journal of the British Psychological Association (August, 1994) dedicated to this topic would attest. In their target article, Sloboda, Davidson and Howe (1994a) argue, partly on the basis of inter-cultural studies, that musical ability is more widespread than 'folk psychology' would have us believe. Individual differences can be accounted for by variance in musical exposure and attention which in turn is driven by motivation. The peer commentaries reject this line of argument as a well intentioned but misguided internment of the nature-nurture debate. Davies (1994) points out that any consideration of individual differences must take genetic variability into account, even in mounting a case for a less marginalised treatment of music education. Radford (1994) extends this position with two linked arguments. First, musical potential and cultural context are mutually interdependent, "neither can be defined without reference to the other" (p. 360). Second, as "music ability refers to degrees of prowess in carrying ... out [music]", even if musicality were a species specific trait, "everyone could not be *equally* musical" (p. 360) (his emphasis). Closer to the main focus of this study, Sloboda *et al* argue that sophisticated musical interpretation, one of the hallmarks of precocious musical talent, is explained as the outcome of instruction which utilises "general principles of perceptual grouping and organisation" in order to make "important structural features of the music more prominent to the listener" (p. 352). Torff and Winner (1994) argue that "children differ enormously in their potential to pick up, retain, and manipulate musical information" (p. 362). These authors note how individual differences in the processing of information required for reading and mathematics can explain much of the variance in school performance in these domains. Similarly "innate differences in proclivity or potential" will make a non-negligible contribution to observed differences in degrees of autonomy in, and rates of, musical learning. "We agree that musical stimulation may well promote musical skill, but there is no reason to assume that all children benefit equally from such stimulation" (p. 362).

The environmentalism of Sloboda *et al* is contrasted by the mentalism of Serafine (1988) who argues that music is purely an act of cognition. Music is an enterprise between a person (listener, composer, performer) and a piece of music which requires some common generic cognitive processes between composition, performance and listening. Thus notes and chords are not the perceptual elements of music. Serafine dismisses current theories of music that posit:

1. music ability is a trait. She argues that perceptual acuity, as a necessary condition for musical ability, is an all-or-nothing phenomenon. Therefore degrees of musical ability cannot be due to variance in acuity, and there is no basis for a trait in music ability.

2. music as communication. A composer's intentions are not always accurately perceived by an audience. Listeners do generate expectancies, but, in contrast to Meyer (1970) where expectancies are based on experience, Serafine argues that expectancies arise from cognitive development.

3. music as reinforced behaviour. Anti-mentalism cannot explain the invention of new musical styles or improvisation.

4. music as nature. If music is the elaboration of pre-existing natural structures, then where do musical elements such as a scale come from?

5. music as sound. Sound is the material of musical thought but not the essence, just as a painting in the visual arts is not the pigment on the canvas.

Whereas the results of this research support a central role for cognition in music perception, the results do not support Serafine's dismissal of other conceptualisations, particularly her points 1, 4 and 5 where individual differences were found. Bregman reports results from laboratory studies which show

> *consistent differences between people. In one experiment, different cues for the grouping of sounds - sequential, spectral, and spatial relations - were pitted against one another. Different people with normal hearing tend to resolve the conflict in different ways. That is, they heard different kinds of illusions. ... This led me to suspect that different people give different weights to the various clues that point to the correct organisation of auditory evidence* (Bregman, 1994: 704).

Bregman concludes that "a more detailed understanding of auditory perception should also make it easier for us to understand how people differ in their auditory perceptual capacities" (p. 703). Cuddy and Upitis (1992) define aural perception as the ability to hear musical relationships in sounded events. Sensitivity to musical structure and a conceptual framework for its interpretation require complex mental processes and representations. The authors offer three guidelines to keep in mind while attempting to measure abilities in music perception:

1. musical context is important;

2. exposure to music, apart from formal instruction, adds to the acquisition of musical knowledge; and,

3. there are many valid ways to evaluate music perception.

Individual differences arise as asynchronous abilities within music domain. Whereas much variance can be attributed to early environment, Cuddy and Upitis present evidence that subject preference for either rhythm or melody is not a function of musical experience.

> *These findings suggest some degree of neural independence for rhythmic and melodic processes. Within a given individual, therefore, certain perceptual components may be privileged over others in the individual's response to music. ... Moreover, strengths or weaknesses in one component may not be predictive of strength or weakness in another* (p. 338).

Such independent multiple dimensions are a feature of the Luria model. Whellams (1973) also found against a unitary structure of musicality. His meta-analysis "does not provide any evidence that general statistical factors have any meaningful connection with what is commonly meant by the term 'musicality' " (p. 9). A more recent meta-analysis by Carroll (1994) was less unequivocal. Of the four factor-types denoted, the largest was for factors which discriminated on two or more tonal qualities such as pitch, timbre, duration, rhythm, intensity etc. Then came factors for frequency-based attributes, temporal and sequential patterns, and musical taste. Carroll comments that previous factor analytic studies into musical talent "prove to be relatively unsatisfactory, in that they fail to yield conclusive statements about the structure of musical abilities" (p. 364). "In the light of the present knowledge (or lack thereof) there is great need for thorough and extensive studies of abilities in this domain" (p. 376). There is evidence that sensitivity to melodic contour and rhythmic regularity are abilities available to most people, including young children (Dowling, 1990; Umemoto, 1990). Accurate pitch discrimination, however, is a necessary condition for musical aptitude (Gordon, 1993). To undergird the main research focus of perception of pitch fluctuations, relationships between abilities in discrimination of pitch, melodic pattern and contour inversion, and the information processing dimensions of the Luria model were also investigated.

A common theme of these investigations was the attempt to understand the form in which musical information is available for cognitive processing. A hierarchical model of information processing requires the correlation of local features at each level to create global constructs as the elements for the next higher level of processing. Parsimony could be maximised where features demonstrate structural self-similarity over ranges of scaling. Mandelbrot (1983) showed that self-similarity, a defining characteristic of fractal form, is ubiquitous in the natural world. Self-similarity is also a property of certain time series known as "fractional Brownian motions" (fBm). Using this concept, Voss (1975) investigated the spectral density characteristics of music. He found that pitch and dynamic fluctuations in music have a 1/frequency (1/f) spectral density function, as do natural contours, and thus reference the natural world through fractal form. A 1/f spectral density function is correlated to some extent over all time scales up to the length of the example. This suggests that in music, autocorrelation processes over all time scales may enable musical information to be processed into functional meaning. Voss found listeners preferred fBm tone series with a 1/f spectral density function over others which were more and less correlated. The present research sought further evidence that autocorrelation structure is a psychologically penetrable characteristic of musical stimuli, by replicating that aspect of Voss's study, and by investigating the relationship of sensitivity to autocorrelation structure with abilities on the Luria model dimensions of information processing, and with more general musical ability.

It should be noted that there is considerable disagreement with the conclusions of Voss in the literature. Nettheim (1992) argues that the time series analysis undertaken by Voss is methodologically flawed, and that real music has spectra more correlated than 1/f. Gilden, Schmuckler and Clayton (1993) present counter evidence for human perception of fractal form in both visual and auditory contours. These authors argue forcefully for perception as an exclusively bipartite process, without reference to the underlying structure of the perceived stimulus. Cohen, Trehub and Thorpe (1989) note that information processing of pitch contours is facilitated where uncertainty is low and redundancy is high. Schmuckler and Gilden (1993), who conducted a limited replication of Voss's study, are somewhat more circumspect. "We find that fractal structure plays a role in discrimination, although it is not an overwhelming source of information", and, "fractal information might simply be another potential source of structure, working in concert (or sometimes in opposition) with other aspects of auditory structure" (p. 658). This research program took some heart from their concluding remarks:

> *[There is] a host of issues concerning the apprehension of fractal structure* per se, *its psychological relevance as a factor in perceptual processing, and its relationship to other factors traditionally thought to play a role in auditory perception. Investigating these issues*

> *promises to be an illuminating task, providing insight into contour perception and auditory processing generally* (p. 659).

Of particular salience for these investigations is the concept of expectancy. According to Meyer (1970) music requires a significant level of information redundancy to maintain the balance between novelty and prediction necessary to hold our interest and maintain our attention. Based on Meyer's theory, Unyk (1990) outlines an information processing approach to expectancy in music cognition. While temporarily stored in the working memory buffer, information from the musical signal is encoded and chunked into musically meaningful units through an interaction with memory traces from the long term memory store. Such an information processing focus is not without certain constraints. Much of the information is not selected for further processing and so "does not become part of conscious awareness" (p. 231).

In contrast, Lufti (1990) found that discrimination of stimuli across several acoustic dimensions was a function of magnitude of the information content. Similarly, Shaw (1983b) argues that information, like certain quantities in physics, is conserved. Shaw notes that information is "not a thing, but a complex function" (p. 341). Detection of information is a function of individual perspective, and as such, is only partially equivalent for different observers. Shaw proposes two information parameters: extensive, which varies continuously on a nominal scale, e.g., frequency; and intensive, which varies discontinuously on an ordinal scale, e.g., pitch class. Conservation of information involves the perceptual transformation of extensive or lower order information, to intensive or higher order information. "The fundamental measurement problem of perceptual theory is to understand precisely how the perceptual system achieves the mapping of extensive parameters of stimulation into the intensive categories of information" (p. 335). Such was the motivation for this programme of research.

1.2 Structure of the thesis

Chapter 2 presents a summary of the neuropsychological work of Luria, and notes Luria's rare but valuable comments on the outcomes of employing music as a stimulus for neuropsychological processing. Luria's model involves three functional units: a sub-cortical unit for arousal and orienting, a posterior cortical unit for information encoding and memorisation, and an anterior cortical unit for directing response. The chapter then examines the considerable research effort in the operationalisation of Luria's model, and its application to the investigation of individual differences in the cognitive abilities of children and their learning outcomes in school settings. Central to this research are psychometric models with factorial representations of two independent dimensions of information processing of the second functional unit, simultaneous and successive synthesis, and a factorial representation of the processes of the third functional unit, executive synthesis.

Chapter 3 reviews the literature on music psychology within an imposed Lurian framework. It is argued that the various evidence for psychological processes in music perception can be classified as examples of simultaneous, successive or executive synthesis. Successive synthesis is used to process serial information such as pitch contour. Simultaneous synthesis is used in long term memory constructs such as scale templates. Executive processing involves the generation of expectancies which has particular salience for the resolution of informational redundancy. This chapter also reviews evidence for relationships between music ability and general intelligence.

Chapter 4 examines efforts to find characterisations of musical signals which could provide low level informational redundancy. The work of Voss in this regard is critiqued in some detail. Candidate characterisations include the fractal dimension, the slope of the spectral density function curve, informational entropy, and the autocorrelation function. It is conjectured that autocorrelation processes contribute to information chunking which creates the perceptual invariants reported in Chapter 3. It is further proposed that autocorrelation structure should be psychologically penetrable.

The first study (N = 151) is presented in Chapter 5. Research questions and hypotheses are formed from the literature reviews in Chapters 2, 3 and 4. Luria model tests for simultaneous, successive and executive synthesis in paper and pencil format are described, and a rationale is given for the use of the Music Evaluation Kit (MEK) Parts I and V. The design and trial of a musical candidate marker test for simultaneous synthesis is outlined, as is the development of a semantic differential instrument to provide a more sensitive replication of the Voss study. The generation of fractal music by algorithm is described, and its similarity to real music is assessed.

The chapter then reports the experimental situation of the first study. The results of testing seven experimental hypotheses are reported. Recommendations for a second study are made.

Chapter 6 presents the second study (N = 135) involving two original computer-based tests to measure sensitivity to autocorrelation structure, one predicted to require predominantly simultaneous synthesis, the other predicted to require predominantly successive synthesis. The design and trial of these instruments is detailed. Research questions and hypotheses are formed from the literature reviews in Chapters 2, 3 and 4, and from the results of Study 1. The experimental details and results of testing six experimental hypotheses are reported, together with interpretations with respect to the literature reviewed earlier, particularly the role of autocorrelation structure proposed in Chapter 4. Recommendations are made for a third study.

Chapter 7 reports the findings of Study 3 (N = 29) undertaken with musically precocious children using the same battery as employed in Study 2. A rationale for this study, including research questions arising from the results of Study 2, is followed by brief profiles of some of the subjects. The measures on simultaneous, successive and executive synthesis, and performance on the sensitivity to autocorrelation structure tasks, of subjects with high musical abilities were compared with those of the Study 2 subjects. The Study 3 data were used to compare competing models of Voss, and Gilden *et al*, for the perception of complex auditory contours in terms of the Luria model.

In conclusion, Chapter 8 summarises the results of the three studies, and discusses their findings. Limitations on the generalisability of the conclusions are made, and some implications for educational settings are noted. The chapter concludes with some suggestions for further research.

Chapter summary

This introductory chapter provided a rationale for this program of research. There is support in the literature for more research to address the problem of how the acoustic properties of a musical stimulus are mentally processed into a hierarchy of stable musical elements. It was argued that an information processing approach is appropriate for such an investigation. The Luria model, as a validated model of information processing, could provide the theoretical framework for interpreting individual differences in musical cognitive abilities. An overview was given of the thesis. Three chapters which review the literature of the Luria model, music cognition and the role of autocorrelational proceses in music perception are followed by the presentation of three studies which replicated and extended previous investigations into the perception of structure in musical stimuli and tested hypotheses concerning individual differences in such perception.

CHAPTER 2

THE LURIA MODEL OF INDIVIDUAL DIFFERENCES

Chapter Overview

This chapter has ten sections. After a brief introduction *Section 2.2* provides an overview of Luria's model of brain functioning as information processing. *Section 2.3* considers Luria's account of music information processing, with a particular focus on cerebral lateralisation. In the next section the compatibility of the Luria model with other contemporary psychophysical models of brain functioning is briefly discussed. *Section 2.5* introduces the literature concerning the operationalisation of the Luria model into a psychometric battery. The following three sections consider, in some detail, the research leading to operationalisation into two, three and four factor models. *Section 2.9* introduces a new operationalisation by Fitzgerald *et al* (1995) in a computer-based adaptive format. The final section compares the operationalised Luria model with other instruments for measuring individual differences in cognitive abilities.

2.1 Introduction

An aim of this program of research was to test the efficacy of a psychometric model of individual differences as applied to musical information processing. A number of psychometric models have been derived from neuropsychological studies of Alexander Luria over several decades c. 1940 - 1975. One lineage of psychometric models, known variously as the Information Integration Approach (Snart, Das & Mensink, 1988), the Luria-Das model (Willis, 1989), the Planning-Arousal-Simultaneous-Successive model (Naglieri & Das, 1988) and the Planning-Attention-Simultaneous-Successive (PASS) model (Das, Naglieri & Kirby, 1994) has been used extensively in research programs over the past twenty years, particularly in Canada at the University of Alberta. A Simultaneous-Successive-Control model (Fitzgerald, 1978, 1990) has also been employed over this period in an extensive program of school-based studies in Australia, mostly at the University of New England. Luria's work also provides the basis for the widely used Kaufman Assessment Battery for Children (K-ABC) (Kaufman & Kaufman, 1983). The psychometric focus of these models is in contrast to the diagnostic focus of the Luria-Nebraska Neuropsychological Battery (LNNB) (Golden, Purisch & Hammeke, 1985) developed for the assessment of neurological trauma.

To be worthwhile in educational contexts a psychometric model must satisfy a number of criteria:

- measures on variables in the model should correlate significantly with measures on standardised tests of educational performance;
- variables in the model should explain significant variance in individual differences in performance of school-based tasks;
- the model should account for individual differences across a wide range of human performance;
- the instruments of the model should be simple to administer in classroom settings.

In addition to such utilitarian criteria, a worthwhile psychometric model should be grounded on a neuropsychological model so that explanations of cognition can ultimately be made in terms of brain functioning. Improvements to a psychometric model, then, should not solely be instrumental but should additionally be informed by developments in neuropsychological and neurophysiological research. The strength of the Luria psychometric model is that, while departing from Luria's clinical neuropsychological model, it is nevertheless grounded in theory and research on brain functioning. Before describing the psychometric model it is necessary, therefore, to provide a brief overview of Luria's work, and to assess its contemporary relevance in the light of more recent developments in the field of neuropsychology.

2.2 Description of Luria's model

Luria's opus focussed on a description of the functional organisation of the human brain. This neuropsychological model was based on Luria's assessment of the cognitive abilities and disabilities of patients with lesions to various locations of the brain, but in particular, the left cerebral cortex. "This model ... provides an excellent example of how research conducted at the anatomical and behavioural levels of analysis can be synthesised" (Willis, 1989:376).

There are three underpinning principles to Luria's neurology. First, brain functioning is undertaken by three distinctive functional units, which have macro rather than micro anatomical localisation. The extensive interconnections of neurones within and between these units explains the second principle, that any particular mental activity involves contributions from all three functional units (Luria, 1970). Furthermore, each area of the brain has a multiple functional role or "pluripotentiality" (Golden, 1987). Third, such cerebral organisation is fundamentally hierarchical. "Concrete systems of matrices, reflecting the 'situational' character of thinking, are gradually replaced by abstract matrices, incorporating a whole hierarchy of 'community relationships' which constitute the fundamental apparatus of categorical thinking" (Luria, 1973:326). Information is increasingly abstracted as it is progressively processed by functional units within the cortex. Such abstraction is an outcome of learning.

The three functional blocks identified by Luria are the subcortical, the posterior cortical and the anterior cortical. The subcortical block consists of the brain stem and the regions of the subcortex, the midbrain, the thalamus and the hypothalamus. This block regulates brain "tone" or wakefulness and the initial response to stimuli. As such this block forms a hierarchical base. "The first functional unit of the brain ... [is] an apparatus maintaining cortical tone and the waking state and regulating these states in accordance with the actual demands confronting the organism" (Luria, 1973:46-47). Its neuronal responses are typically gradated rather than of the "all or nothing" response of cortical neurones.

The second block involves the parietal, occipital and temporal lobes of the posterior cortex, and has the specific function of information processing, i.e., the input, storage and analysis of sensory data. Areas of modal specificity can be identified within the block for the processing of information passed on from visual, acoustic, tactile, kinaesthetic and olfactory receptor cell complexes which initially process modally specific stimuli. Functionally, the second block is hierarchically partitioned into three zones:

> *a primary zone that sorts and records the sensory information, a secondary zone that organises the information further and codes it, and a tertiary zone where the data from different sources overlap and are combined to lay the groundwork for the organisation of behaviour* (Luria, 1970:67).

Each lobe has primary and secondary zones which retain modality, e.g., visual information in the occipital lobe and auditory information in the temporal lobe. "The primary ... zones discriminate among stimuli and influence sensory reception to ensure optimal perception. The secondary ... zones ... are adapted to relaying afferent impulses to the tertiary zones for further synthesis" (Willis, 1989:377). The tertiary zone integrates information across modalities. This zone occupies the angular gyrus where the three lobes of the posterior cortex overlap. Furthermore, "these functionally organised zones of the cortex constituting second brain systems work according to the principle of diminishing modal specificity and increasing functional lateralisation" (Luria, 1973:79). By this principle the functionality of higher order cognition has distinctly different contributions from the left and right parietal lobes. "The left (dominant) hemisphere ... begins to play an essential role not only in the cerebral organisation of speech, but also in the cerebral organisation of all higher forms of cognitive activity connected with speech - perception organised into logical schemes, active verbal memory, logical thought" (Luria, 1973:78). This has particular salience to the perception of music.

> *Disturbances of phonemic hearing which are a direct result of a lesion of the secondary zones of the temporal cortex ... arise only in lesions of the left temporal region, and are never found in lesions of the right temporal lobe. For this reason lesions of the right temporal lobe ... are manifested sometimes as a disturbance of the hearing of music, which has been called sensory amusia. These differences between the functions of the left and right temporal regions are among the most fundamental differences observed in the functional organisation of cortical systems* (Luria, 1973:137).

Nevertheless, Luria argues that all afferent information processing of the second functional block can be categorised into two independent factors: simultaneous synthesis and successive synthesis. Simultaneous synthesis refers to the organisation of information into quasi-spatial arrangements which afford surveyablitity. Luria (1966a) reports the diagnoses of patients with lesions to the occipito-parietal area who could recognise individual words or figures, but had difficult with tasks such as " drawing a triangle below a circle and a triangle to the right of a cross", and "constructions ... with an attributive genitive case (... the dog's master, or the master's dog). Before such expressions can be understood, the logical synthesis of the elements into an integral whole is required" (p. 156-7). Luria suggests that these patients are impaired in their ability to turn information received sequentially into synchronic quasi-spatial arrangements. Golden (1987) notes that "the tertiary areas of the second unit, located primarily in the parietal lobe of the two hemispheres, are responsible for cross-modal integration and simultaneous (as opposed to sequential) analysis of input from the sensory modalities" (p. 101). Luria states "the tertiary zones of the posterior cortical region play an essential role in the conversion of concrete perception into abstract thinking" and "the principle role of these zones is ... the conversion of successive stimuli into simultaneously processed groups" (Luria, 1973: 73-74). Simultaneous synthesis, then, is a more dominant functioning than successive synthesis because it is the predominant process of the tertiary zones. Crawford (1986) reports experimental support for Luria's (1973) proposal that abilities to regulate cognitive processes are necessary to ensure the inhibition of immediate responses so that simultaneous processing can occur. Such self regulation is used to enhance efficiency of simultaneous processing in the case of complex tasks.

Successive synthesis refers to the organisation of information into temporal wholes, in which the elements are consecutively connected. "Each link integrated into a series can evoke only a particular chain of successive links following each other in serial order" (Luria, 1966:77). Successive synthesis is temporally integrative. At the secondary zone, examples of successive synthesis include the coding of repeated rhythm patterns, sequences of words, numbers or pictures. The acoustic secondary zone in the temporal lobe organises 'raw' sounds into pitch, timbre and rhythm etc. The tertiary zone is responsible for higher order tasks such as the recoding of internal speech for self expression, and following verbal instructions (Luria 1966b). With music, the tertiary zone analyses the output of the secondary zone into a melody, and not merely a series of isolated tones.

This simultaneous/successive categorisation, more than any other aspect of Luria's work, has led to the formation of psychometric instruments, although later developments have incorporated more of the orientation of the three blocks model.

The third block, the anterior cortical unit including the frontal lobes, in contrast with the second block, is responsible for efferent information processing, i.e., the formation of intentions and programs for behaviour. This third functional block is responsible for "the programming of human activity, collating the effect of action with initial intention, and regulating and controlling mental processes" (Luria, 1966b: 67). In further contrast to the other blocks, hierarchical organisation is descendent rather than ascendant, i.e., the tertiary zones, which have an executive functioning, inform the secondary zones which organise motor activity, and which in turn inform the primary zones which are responsible for the execution of motor activity. Much of the output of these zones is also characterised by successive synthesis, e.g., a spoken response, or playing a piece of music. However, it is the tertiary zone of this functional block that is of particular importance for the purposeful conduct of intellectual activity.

> *The tertiary portions of the frontal lobes are in fact a superstructure above all other parts of the cerebral cortex, so that they perform a far more universal function of general regulation of behaviour than that performed by the ... tertiary area of the second functional unit* (Luria, 1973:89).

It is the particularly high density of the connections of the frontal lobes with the other blocks that allows this block "to play a decisive role in the formation of intention and programs, and in the regulation and verification of the most complex forms of human behaviour" (Luria, 1973:84). In particular, selective attention, a contingent attribute for efficiency in learning, is a responsibility of this functional unit. "The major tasks of this area are planning, evaluation, temporal continuity, impulse and emotional control, focussing of attention, and flexibility" (Golden, 1987:101).

Most important for Luria's description of brain functioning is the role of learning in the determination of behaviour. Luria (1966a) regards higher human mental functions as "complex reflex processes, social in origin, mediate in structure, and conscious and voluntary in mode of function" (p. 32). Naglieri and Das (1988) note that "Luria's functional systems are dynamic in that they respond to the experiences of the individual, are subject to developmental changes, and form an interrelated system" (p.39). By 12 months after conception, the first unit and the primary zones of the second and third functional units are fully operational in the infant brain. The functional efficacy of these areas is determined by genetics and morphogenic variation. The subsequent neurophysiological maturation of the secondary and tertiary zones of the second and third units, however, "serves only as a potential basis for the emergence of skills mediated by [environmental experience]. Without the appropriate experience, the abilities will not develop" (Golden, 1987:103). This is particularly critical for executive synthesis given that the tertiary zone of the third unit only completes its neurophysiological development around age 10-12 years. "Physiological changes produced by a spoken instruction and lying at the basis of voluntary attention, are formed only gradually, and do not appear in a precise and stable form until the age of twelve to fifteen years" (Luria, 1973:270).

The Luria model, in parallel with the developmental psychology of Piaget, suggests that abilities on simultaneous synthesis and planning strengthen with age, and become more differentiated from successive processing. For example, Crawford's (1986) results suggest that prolonged differences in social experience effect the simultaneous processing ability of primary school aged children. This process is iterative; high ability on simultaneous synthesis produce well established frames of reference to guide the internal processing of new information. Declarative or conceptual knowledge, gained through past experience, is used through the function of the tertiary zones of the second unit to guide the simultaneous processing of new afferent information. In Piagetian terms, new knowledge is constructed through the processes of assimilation and accommodation.

Thus, different children who display similar behaviour, e.g., obtaining a similar test score, may do so as a consequence of quite different information processing strategies. Luria's model, then, offers a potential framework for the investigation of individual differences in children. However, in undertaking such an investigation, consideration of the developmental stage of the subjects is most important. Furthermore, the researcher interested in differences in abilities needs also to be aware that pluripotentiality may allow subjects much older than 12 years to 'compensate' for those cognitive functionings which are weaker than others. The operationalisation which is closest to the model's clinical origins is the Luria-Nebraska Neuropsychological Battery (LNNB), which has been revised specifically for younger children as the LNNB-C (Golden, 1987). In a study using the Weschler Adult Intelligence Scale (WAIS) and the LNNB, Vannieuwkirk and Galbraith (1985) found a significant age-effect for the LNNB with young and old adults: older subjects performed more poorly. However, Boyd and Hooper (1993) found less of an age-effect using the LNNB to predict WISC-R IQ scores of adolescent psychiatric patients aged from 12 to 16 years.

Much of the literature concerning the LNNB is critical of the adequacy of its operationalisation (Spiers, 1981; Delis and Kaplan, 1983). Bryant, Maruish, Sawicki and Golden (1984) argue that these critics have misunderstood the construction of the LNNB scales. "Each scale samples a spectrum of tasks that potentially involve a target skill or specific combination of skills" (p.

446). Internal scale validity is compromised to some extent in the interests of breadth of clinical experience. More recently, assessments by the LNNB have been facilitated via a computerised interpretation of this battery (Horton, Vaeth & Anilane, 1990). Diagnoses were compared with case histories and CAT scan results. The hit rates reported were presence of brain damage 80%, extent of brain damage 60%, and laterality 71%. This last result was a considerable improvement over other algorithmic approaches to such diagnosis. The LNNB also involves a wider range of tasks than the psychometric batteries reviewed in Chapter 3, and includes scales for rhythm perception and production.

2.3 Music information processing within the Luria model

Luria's description of the organisation of auditory perception begins with the transmission by auditory nerve fibres of impulses from frequency-sensitive cells of the cochlea. The auditory pathway runs through the medial lemniscus to the medial geniculate body and terminates in the projection zones of the auditory cortex. Like in the projection zones of the visual cortex, somatotopical structure is preserved. Unlike the binocularity preserved by their visual counterparts, the projection zones of the auditory cortex do not preserve distinct representations of each ear. Furthermore, "the temporal projection cortex not only transmits acoustic excitation to the cortex, but also prolongs and stabilises its action, making it more constant in character and amenable to control" (Luria, 1973:129). Thus the secondary functional zones synthesise auditory information for recognition and interpretation.

> *The secondary zones of the auditory cortex play a vital role in the differentiation of groups of simultaneously presented acoustic stimuli and also of consecutive series of sounds of different pitch or rhythmic acoustic structures* (Luria, 1973:132).

Furthermore, "their importance lies in the fact they are the fundamental apparatus for the analysis and synthesis of the sounds of speech." This is particularly the function of the left temporal lobe. Lesions to the right temporal lobe do not affect speech but do impair the ability to perceive music.

> *Lesions of the left temporal lobe ... do not give rise to similar disturbances of musical hearing. This is reflected both in the integrity of the intonational-melodic components of the speech of patients with sensory aphasia and in the integrity of their singing, which is in sharp contrast with their disturbed phonemic hearing. ... a severe disturbance of speech hearing ... in a composer of music left the musical hearing intact to such a degree that,*

> *although suffering from severe sensory aphasia, the patient could still write intricate musical compositions* (Luria, 1973:142).

Luria emphasises that speech and music, although modally similar, are processed quite separately.

> *To the unprejudiced observer, musical hearing and speech hearing may appear to be two versions of the same psychological process. However, observations on patients with local brain lesions show that destruction of certain parts of the left temporal region leads to a marked disturbance of speech hearing ... while leaving musical hearing unimpaired. ... This means that such apparently similar mental processes as musical hearing and speech hearing not only incorporate different factors, but also depend on the working of quite different areas of the brain* (Luria, 1973:41).

This may seem to lend support to the recently popularised Seven Intelligences model of Howard Gardner (1993) wherein music intelligence and logico-linguistic intelligences are independent constructs. The notion of separate intelligences, however, still begs the question of underpinning processes. In particular, investigators using the operationalised model have not analysed the processing of musical information any further. Given that music, amongst other things, can be represented by a simpler symbol system than language or mathematics, is culturally ubiquitous, and is a vehicle for prodigious individual differences, this seems an important omission from the psychometric research effort.

Luria's observations could suggest a right hemispheric system for the coding of non-linguistic information such as music. By extension, the right temporal lobe could play a parallel role in organising musical information for efferent responses. Such a suggestion is supported by two electroencephalographic (EEG) studies which found excitation in the right parietal and frontal lobes in response to cadential expectancy. Janata and Petsche (1993) tested musically trained subjects with cadences which were either resolved musically or not. EEG parameters differed depending on whether the expectancy generated by the musical context was violated or fulfilled. The parameters were also sensitive to the ease with which subjects classified such musical resolution. The authors conclude:

> *In addition to confirming that a form of expectancy operates in musical contexts, the results point towards the brain structures responsible for the processing of complex musical stimuli. In particular, EEG parameters changed not only at recording sites located above the auditory cortices, but also at sites above right frontal and parietal regions* (p. 303).

Clearly, generating and updating expectancies is central to understanding and appreciating music. With their rich connections to the centres for emotional responses, and the other functional blocks, the frontal lobes are well functionally located to provide such integration.

Tervaniemi, Alho, Paavilainen, Sams and Naatanen (1993) compared subjects with and without absolute pitch but matched for music training on the event-related brain potential (ERP) component of mismatch negativity (MMN). MMN reflects a mismatch process between deviant and standard auditory stimuli, and thus correlates with pitch-discrimination performance. There were no significant differences between the two groups on pitch discrimination but subjects with absolute pitch had a smaller MMN. These results suggest that pitch discrimination and identification are based on different brain mechanisms. These results support earlier findings by Crummer, Hantz, Chuang, Walton and Frisnia (1988) who found that P3 ERP waveforms between musicians and non-musicians were different. The P3 ERP "is used as a measure of the manifestation of a cognitive subroutine invoked whenever there is a need to update ... working memory" (Frisnia, Walton & Crummer, 1988: 104). Working memory is where information from external stimuli interacts with information from long-term memory. Crummer *et al* suggest that musicians have different memory strategies available.

In contrast, Fiske (1987) appeals to the law of the excluded middle to argue that the cognitive structure for perception of music must be the same for expert and novice alike. He proposes a model for melodic discrimination based on studies of response times of musically trained subjects to melodic discrepancy. In this model "discrepancy detection and discrepancy identification represent two separate decision-making activities" (p. 35). Lateralisation studies by Hassler (1990) present counter-evidence to Fiske's logical position. Her data

> *support the assumption that left-hemisphere and right-hemisphere functions contributing to processes associated with verbal processing are more effectively integrated in musicians*

> *than non-musicians ... The data also can be interpreted as an indication that musicians have anomalous dominance, i.e., they have more symmetric brains* (p. 13).

Similar findings are reported by Strong (1992) in a study comparing the laterality of normal and learning-disabled (LD) subjects on verbal and music perception tasks. Strong concludes that the differences in melodic perception between LD and normal subjects lay in "the manner the tonal patterns were processed perceptually, in addition to, or instead of, any differences in hemispheric asymmetry for melodic perception" (p. 149). Strong cautions that hemispheric specialisation may be an artefact of research procedures and reporting, and that lateralisation should be conceptualised along a continuum, "with hemispheric preferences based upon an interaction of stimulus characteristics and specific task demands" (p. 149).

These findings seem to contrast Luria's (1973) on the localisation of music processing. However, for Luria, the key to increasing laterality is the extent to which the function is dependent on encoding through speech.

> *The principle of lateralisation of higher functions in the cerebral cortex begins to operate only with the transition to the secondary and, in particular, to the tertiary zones which are principally concerned with the coding ... of information reaching the cortex, and performed in man with the aid of speech* (Luria, 1973: 78).

Consistent with Luria, Umemoto (1990) found a strong relationship between language and musical judgement for complex musical concepts such as the suitability of a particular timbre. It was at the level of the primary zones that Strong found a left hemisphere preference for the perception of both tonal and verbal stimuli. He suggests that similar analytic processes are being utilised for the encoding of each type of information. Strong recommends further studies into the relationships between laterality and learning.

The interaction of prior learning with cerebral organisation was the research focus of Gardner, Silverman, Denes, Semenza and Rosenstiel (1977) in an investigation of the cerebral location of amusia. Whereas the right hemisphere "plays a somewhat more important role in the processing of musical and other non-linguistic sound patterns", the researchers found that "amusia seems to result more frequently from dominant rather than minor hemisphere lesions" (p. 243). Learning plays a significant role in determining the manner by which music is processed. "Musically sophisticated individuals are likely to perceive musical stimuli in a more analytic manner, and to rely more heavily on the dominant hemisphere" (p. 243). The authors explain this as indicating the use of simultaneous synthesis in music information processing. The more "puzzling" result was that, contrary to earlier reported evidence, the musical comprehension of posterior aphasics was superior to that of anterior aphasics on a connotation test, but inferior on a denotation test. These results, however, are not puzzling if interpreted by the Luria model; anterior aphasics with deficit successive processing have impairments in the verbal abilities necessary for a knowledge of lyrics, whereas posterior aphasics with deficit simultaneous processing have impairments in the abilities necessary for a situational analysis.

Das, Kirby and Jarman (1979) suggest that the apparent contradiction between lateral and sagittal organisational emphasis could be resolved by assuming both organisations exist: the temporal-parietal-occipital of the non-dominant hemisphere would be more parallel in functioning than the corresponding area of the dominant, while the fronto-temporal area of the dominant would be more serial than the non-dominant. That is, the non-dominant hemisphere has more responsibility for simultaneous synthesis than the dominant, and the dominant hemisphere has more responsibility for successive encoding than the non-dominant.

Minsky (1985) argues that due to the multiplicity of brain parts, hemispheric similarity is predominant, with many agencies duplicated on each side. Hemispheric differences may arise with higher order functioning to avoid conflicts between competing agencies.

> *Eventually the adult managers for many skills would tend to develop on the side of the brain most concerned with language because those agencies connect with to an unusually large number of other agencies. The less dominant side of the brain will continue to develop, but with fewer administrative functions - and end up with more of our lower-level skills, but with less involvement in plans and higher-level goals that engage many agencies at once* (Minsky, 1985:116).

Golden's (1987) interpretation of Luria's position on lateralisation is consistent with Minsky. The dominant hemisphere operates as a discrete analyser and is predominant with material which is very familiar. The non-dominant hemisphere is less structured for localised functioning, and so operates in a more holistic manner suitable for the processing of novel stimuli. Thus musical interpretation, usually a function of the non-dominant hemisphere, becomes increasingly a function of the dominant hemisphere with musical accomplishment and experience.

However, Willis (1989) highlights several difficulties from the literature with lateralisation models of cognitive processing. Information can readily be transferred to the ipsilateral hemispheres via the commissural projection pathways, particularly if only one sub-component rather than the whole of the processing task is performed by one hemisphere. Functional localisation should be seen as contributory and subservient to the processing whole. Indeed, lateral organisation may be the means by which interference from concurrent processings is minimised, rather than a substrate for specialisation.

> *Cerebral specialisation is viewed as a kind of neural separation between complementary component operations that ... ultimately are aggregated to result in a unitary pattern of behaviour. The primary advantage of this initial separation of component operations is that it protects the distinct, but complementary, contributions of various operations from mutual interference* (Willis, 1989: 376).

As none of the operationalisations of the Luria model [described below] explicitly measure lateralisation, this issue can be left unresolved. More importantly is a consideration of the extent to which the Luria model is consistent with some of the more recent neuropsychological literature which is briefly reviewed in the following section.

2.4 Neurological mechanisms

The search for neural mechanisms has led away from specific localisation of mental functions (such as the proverbial grandmother cell) and towards the concept that higher level or complex phenomena are emergent properties of massively parallel networks of lower order behaviour (e.g., Rose, 1993; Mainzer, 1994). The literature has necessarily been multidisciplinary, and has been particularly informed by work in the field of artificial intelligence on the functioning of neural nets (e.g., Wiles, Latimer & Stevens, 1994).

> *The basic idea is that our experience of concepts, objects and events is represented by a pattern of activity in a kind of neural network. Occurrence of a pattern within the network*

affects the connections between elements within it in such a way that the network is capable of storing and processing information (West, Cross & Howell, 1987:20).

Such storage and processing involves both the perception of afferent stimuli and the recall of associated memory traces. Perception of stimuli is dependent on short-term memory whereas recall involves functioning of long-term memory. The extent to which both of these types of mental representations utilise the same processing functionalities remains an open question. Long-term storage presumably involves some alteration of the connectivity between nodes of a neural net, whereas short-term memory "involves continued activation of the nodes ... once the stimulus has gone" (West, Cross & Howell, 1987:23). Such a conceptualisation allows for at least two ways in which memory can underpin higher level behaviour such as the interaction of learned music constructs with performance improvisation, or composition. Mentally stable structures are constructed through enculturalisation, in contrast to spontaneous creativity arising from systemic inhomogeneity or processing flexibility of "layers of interconnected general purpose processors ... which combine information coming into them in various ways to produce particular patterns of output" (West, Cross & Howell, 1987:23). Evidence from music cognition research [Chapter 3] is consistent with these descriptions.

As these mental processes are themselves subject to human perception, much of the focus of recent neuropsychological research has been on the "problem of consciousness" (Crick & Koch, 1992). Consciousness has been described as a self-perceptive feedback process. The process is iterative in that it includes the perception of one's own mental processes including consciousness itself (Hebb, 1961). The thrust of recent research has been to regard mental imagery as a complex emergent property of the localised neural functioning involved in the processing of sense data (Bossomaier, Pipitone & Stuart, 1993; Waldrop, 1992). Such mechanistic modeling informs Luria's basic thrust that higher order cognitive activity is manifest from the processing of lower order information.

Freeman and others have demonstrated that olfactory processing as measured by EEG traces can be represented by chaotic attractors; high fractal dimension strange attractors for the resting but alert state, stable limit cycles of lower fractal dimension for familiar odours, and higher fractal dimension attractors for novel odours (Freeman, 1990, 1992). [A review of the concepts of 'fractal dimension' and 'chaotic attractors' is presented in Chapter 4.] Such a model is consistent with a constructivist paradigm of assimilation and accommodation (Skarda & Freeman, 1987). Freeman argues that preattentive vision is a parallel process with olfactory detection, and that the chaotic attractor model is applicable to cognition of all modalities including audiation (Freeman, 1990, 1992). The emergence of individual differences in such cognitive functionalities, then, would be a consequence of variance in the efficiency of cerebral attractor creation and perturbation. That is, as Luria's work demonstrates, psychological variance arises from neurological variance.

This approach explains individual cognitive differences as an interaction of both genetic disposition and environment (Kimura, 1992). The strength of particular attractors, and the variety of possible attractors, must be determined by the neural structure present, which in turn must in part be determined by morphogenesis controlled by genetic coding. However, by Hebb's law, neural connections are strengthened under mutual reinforcement, i.e., learning. Such physiological changes to the neural apparatus would produce changes in neuronal-column signal strength, which in turn would affect the consequent attractors. Evidence for such an explanation of individual differences in the perception of music is presented by Birbaumer, Lutzenberger, Rau, Mayer-Kress, Choi and Braun (1994). The perception of musical structure, its construction into remembered musical elements, and the higher order activities of anticipation, planning and understanding, are all undertaken by specific assemblies of cortical cells, strengthened through excitatory stimulation from other connected assemblies as theorised by Hebb (see also Burgess, 1990; Mainzer, 1994; Stuki & Pollack, 1992). Birbaumer *et al* hypothesise that individual differences in musical expertise and preference for complex classical music over simple popular music should manifest in different resonance dynamics of these assemblies specialised for music perception through preferred musical structures. This hypothesis was tested on two groups of subjects, musically sophisticated and unsophisticated, with synthesised tone sequences across three conditions: periodic, intermittently chaotic, and highly chaotic [some features of chaos theory are outlined in Chapter 4]. Using EEG data these researchers found "fundamental differences in brain response of musically sophisticated and less trained subjects" (p. 12). Musical sophisticated subjects showed higher dimensional complexity in the EEG traces of their prefrontal regions. These results are similar to those in other studies investigating individual differences in intelligence. "The reference for complex music in intelligent groups reflect their brains' increased associative diversity with a high number of independent assemblies and therefore music memories" (p. 13). The authors note that all of the relevant mental processes required for perception of complex stimuli "involve delay of immediate reinforced behaviour and active working memory. Both cognitive functions are more or less exclusively frontally located" (p. 13). These functions are operationalised in the Luria model as the attention/control dimension, or the process of executive synthesis.

2.5 Operationalisation of the Luria model

Extensive psychometric work in operationalising the cognitive aspects of the Luria neuropsychological model has been undertaken by researchers, notably Das and others in Canada (Ashman & Das, 1980; Cummins & Das, 1978; Das, 1973; Das & Heemsbergen, 1983; Das, Kirby & Jarman, 1975; Das, Kirby & Jarman, 1979; Das & Molloy, 1975; Das, Naglieri & Kirby, 1994; Dash & Mahapatra, 1989; Kirby & Das, 1990; Naglieri, 1989; Naglieri & Das, 1988; Naglieri, Das & Jarman, 1990; Snart, Das & Mensink, 1988) and Fitzgerald and others in Australia (Crawford, 1986; Elliott, 1990; Fitzgerald, 1978, 1990; Geake, 1991; Green, 1977; Hunt, Randhawa & Fitzgerald, 1976; Klich, 1983; Leasak, Hunt & Randhawa, 1982; Ransley, 1981; Try, 1984; Tulloch, 1981; Walton, 1983; Watters, 1993; Woodley, 1993). The research focus has evolved from the validation of marker tasks within the Luria theoretical framework by using factor-analysis, to the application of the subsequent operationalised model to account for individual differences in cognitive abilities and educational performance. Luria, it could be noted, initially seemed sceptical about such endeavour:

> *It would be wrong to underestimate the importance of the work done in this direction by the various schools of 'factor analysis'. However, it would be equally wrong to suppose that the mathematical methods used by these schools are a natural way of obtaining the solution to the problems which arise* (Luria, 1973:343).

Here Luria is critical of factor analysis as a device to understand the organisation of the mind. In doing so Luria sides with the 'factors-are-mathematical-constructs' position over the 'factors-are-real' position in the debate over the ontological status of factor analysis (Gorsuch, 1988).

Factors are not so much representations of cognitive realities as ways in which data can be interpreted. By employing principal components analysis with orthogonal rotations, early versions of the operationalised models are consistent with Luria's position. In fact Luria greeted the early study of Das with enthusiasm: "the [factor analytic] approach ... showed its reliability and validity in the studies of neuropsychological syndromes; ... in a direct approach with factor analysis those ideas are of a certain value" (personal correspondence 1975, reprinted in Das, Naglieri & Kirby, 1994). The later PASS models have been developed through the use of exploratory factor analysis, and lay some claim to representation of cognitive organisation (Naglieri, 1989).

Luria's "natural way" involved syndrome analysis of individual patients. His categorisation of information processing into the two independent modes of simultaneous and successive processing was based on his interpretation of deficit cognitive functioning associated with specific locations of cortical lesions. Lesions in the occipito-parietal areas produced dysfunctions in patients' abilities to perform spatial and quasi-spatial tasks, whereas lesions localised in the temporal lobes produced dysfunctions in patients' abilities to perform tasks which required sequential or serial processing. An important assumption of the Luria model is that such syndrome analysis can be used to describe aspects of normal cognitive functioning, and that syndromes could be regarded as the lowest extremes on dimensions of individual differences.

These functional categories, referred to as "syntheses" in the psychometric model, can be more fully described with recourse to Luria's hierarchical organisation within the second functional block. Reflecting this hierarchical zonation, simultaneous and successive synthesis are each manifest on three levels: a perceptual level for the processing of sensori-motor stimuli; a mnestic level for the organisation of memory, importantly involving a process of coding; and, an intellectual level for higher order analysis required in language understanding and problem solving. What is common to each syndrome is the nature of the processing requirements rather than the nature of the stimulus.

Simultaneous synthesis is the process of arranging input data, often necessarily sequential, into a simultaneous or "surveyable" array of interrelated elements. This functioning is characteristically spatial or quasi-spatial. At the perceptual level this involves combining perceived components into a cohesive whole, or recognising that "elements share a common characteristic" (Das, Naglieri & Kirby, 1994: 15). Examples include copying a design, locating a sound in space, or recognising an object by touch. At the mnestic level, memory traces are introduced. Opticomnestic synthesis, for example, is required for such tasks as drawing plans, navigating through familiar surroundings and reproducing drawings from memory. At the highest level, simultaneous synthesis is required for tasks involving quasi-spatial relationships such as determining place value in arithmetic, and in logic and grammar, e.g., understanding the distinction between "father's brother" or "brother's father".

Successive synthesis involves the organisation of sequential input into a meaningful whole over time; the production of a "smooth kinetic melody" (Luria, 1966: 87). Acoustic and kinaesthetic modalities are predominant. For example, comprehension of a verbal instruction depends on successive processing. It is difficult to distinguish perceptual and mnestic levels of successive synthesis. Operation on both levels seems to be required for the correct sequencing of, say, musical sounds in perceiving a melody, or of the correct sequencing of steps in learning a dance. At the highest functioning level, successive synthesis is required for the comprehension of syntax, for the smooth development of thematic narration, and for the transference of ideas expressed in the speech of others into thought.

Among the challenges for those seeking to operationalise the Luria model are some difficulties with interpretation of Luria's conceptualisations of simultaneous and successive synthesis. At the highest level of abstraction, successive synthesis seems indistinguishable from simultaneous synthesis. If so, then this would support Golden (1987) in suggesting that simultaneous synthesis is essentially hierarchical over successive synthesis, and that all tertiary zone activity is essentially simultaneous. Crawford (1986) suggests that Luria associates simultaneous synthesis with both the encoding of visual/spatial information and the development of abstract holistic mental constructs. Successive synthesis is more concerned with the encoding and initial processing of sequential stimuli, particularly acoustic. But even spatial information has to be scanned and thus put into a serial order for input. The key distinguishing feature is whether that serial order is of importance. With visual scanning the order of the partial images is usually not of importance. Simultaneous synthesis at the primary and secondary zones, then, would be associated with the reconstruction of quasi-spatial information from a necessarily sequential input to create the impression of holistic perception. The two constructs for simultaneous synthesis could be regarded as convergent if simultaneous synthesis employed common *modus operandi* of integration to the different inputs of the primary, secondary and tertiary zones. In the tertiary zones simultaneous synthesis operates on the output from both secondary zones (simultaneous and successive) to construct suitable mental abstractions with which to determine an appropriate behavioural response.

Ransley (1981) points out another apparent confusion in Luria's account of these syntheses. Whereas Luria describes each as an afferent synthesis, i.e., concerned with input, the examples Luria uses are frequently in terms of efferent synthesis, i.e., concerned with output. Crawford (1986) paraphrases examples of behavioural criteria for distinguishing the qualitative difference between the two processing dimensions. Repeating an instruction verbatim is indicative of successive synthesis; expressing the instruction in one's own words but with correct meaning is indicative of simultaneous synthesis. This example suggests that successive synthesis can maintain independence from simultaneous synthesis at least in the determination of response behaviour.

With the measurement of individual differences on simultaneous and successive synthesis through responses to psychometric tests, Snart, Das and Mensink (1988), and Das *et al* (1994) argue that the domain in which any task is located, pictorial, verbal, auditory etc., should also be taken into account. Simultaneous and successive synthesis are best conceptualised as categories of processing.

> *At the broadest level, simultaneous and successive processing can be seen as types of coding underlying all forms of behaviour. Within each type of coding, tasks from similar areas (e.g., reading or spatial tasks) would be expected to be more related to each other than to other manifestations of the same type of coding from a different area. For this reason, for instance, we would expect measures of simultaneous coding using spatial content to be more highly correlated with each other than with a simultaneous coding test that used verbal content* (p. 64).

Their advice was heeded during this investigation by using tests for individual differences with verbal and spatial content [Chapters 5, 6 and 7].

2.6 Psychometric operationalisation with two factors

The first attempts to psychometrically operationalise this model concentrated on simultaneous and successive synthesis. The aim was to use tests which measured similar attributes to those employed by Luria but adapted for group testing. It was assumed that the lowest performance on such tests would indicate a similar level of neural functioning to Luria's patients with mild syndromes. Typical early tests to measure simultaneous synthesis were figure copying and completion instruments such as *Raven's Progressive Matrices*. Typical early tests to measure successive synthesis were various serial and free recall instruments such as forward and reverse digit span. Tests which consistently loaded on interpretable factors for simultaneous and successive synthesis were subsequently employed as marker tests for those factors in other studies.

Das (1973) employed the Luria model in a cross-cultural study comparing Indian with Canadian school children. A principal components factor analysis produced two factors interpretable as simultaneous and successive synthesis. In commenting on the juxtaposition in importance (explained variance) of the process factors Das notes that Indian pedagogy relies more on rote learning than Western education and consequently Indian children might be expected to show some preference for sequential synthesis. Other cultures might also be expected to display cognitive stylistic preferences. Das, Kirby and Jarman (1975) report testing the generality of the Luria model across IQ scores by factor analysing cognitive test scores of "normal" 2nd and 3rd Grade children and "retarded" children of matched mental age. Two factors operating in each group were best explained as representing the processes of simultaneous and successive synthesis. Das and Molloy (1975) sought evidence for simultaneous and successive synthesis factors across different age groups by comparing the patterns of factor loadings for a battery of cognitive tests for boys aged six and nine years (school grades 1 and 4). Three factors were evident for each age group. They were interpretable within the Luria model, the third factor being labelled "speed". The general similarity of the factor loading patterns indicated that children in the age range sampled utilised similar cognitive processes to accomplish the cognitive tasks tested. The authors note the important implications for pedagogy. Thus even at this exploratory stage, the Das battery showed potential for assessment in school contexts. Such applications are reviewed below.

These early studies were not without criticism. Reporting a replication study, Vernon, Ryba and Lang (1978) favour a "hierarchical taxonomy of mental abilities" (p. 12) over a two factor model which they regard as too simplistic. In particular, they see the notion of successive synthesis as problematic. Synthesis requires some combination to construct a whole which is more than the sum of its parts. The measurement of successive synthesis by recall tasks, however, does not require transformation or recombination of the source information. A similar criticism can be levelled at figure copying tasks as tests for simultaneous synthesis. Ransley (1981) argues that it was the type of processing required, rather than the amount, that distinguishes Luria's dimensions from those of other models. Serial recall tasks such as digit span and word span, which require successful sequencing of elements, satisfy Luria's concept of successive synthesis; free recall tasks do not. Furthermore, such tasks would only necessitate processing by the secondary mnestic zone. Tasks need to be developed which require processing by the tertiary zone, such as the analysis of narrative. With simultaneous synthesis, matrix copying demands surveyability, but at best would be processed by the secondary zones. Matrix inversion tasks, such as developed by Fitzgerald (1978), would require tertiary zone processing.

A characteristic of later Luria model batteries is the absence of tests for processing speed *per se*. Vernon, Nador and Kantor (1985) report further evidence in addition to an already "impressive body of research supporting the general hypothesis that the speed or efficiency with which persons execute a small number of cognitive processes - including encoding, short-term memory processing, and long-term memory retrieval - is quite highly related to their performance on tests of intelligence and mental ability" (p. 357). A number of marker tests in the Fitzgerald paper and pencil battery are timed. These include the *Fitzgerald Matrices A and B*, and the tests of *Number and Letter Recognition* [Chapter 5; Appendix E]. More recently Vernon and Mori (1992) report correlations of peripheral nerve conduction velocities with intelligence test scores. The authors argue that the transmission rates of nerve impulses may be a limiting constraint to information processing rates, and also to intelligence in general. Individual differences, then, may have a genetic basis in neural efficiency, a position consistent with that of Hebb.

The independence of Luria's functional dimensions of simultaneous and successive syntheses is operationalised by employing principal components analysis to form orthogonal factors from the marker test scores. The intention in developing marker tests is that the marker test scores represent pure measures of their dimension. Thus the cross-loading of marker tests on the "other" factor may be problematic. It is certainly symptomatic of Luria's principle that both cognitive functional dimensions contribute to any particular intellectual task. Ransley (1981) notes that it is difficult to conceptualise tasks which could be undertaken using purely one dimension or the other. The serial order of digits, for example, can be remembered through visualising their position in a linear grid, using simultaneous synthesis, while figure copying can be executed one line at a time in a serial order, using successive synthesis. So that individual difference variance on one dimension is not compromised by a compensatory contribution from the other, the method of administration of marker tests, Ransley suggests, is of critical importance.

Kirby and Das (1990) considered process interdependence in their review of the operational model. They describe how successive and simultaneous syntheses are employed in a collaborative cycle on any complex coding task. With reading, for example, "a sequence of syllables or sounds must be coded (successive) so that a word may be recognised (simultaneous), and then a sequence of words (successive) may be recoded as a phrase (simultaneous)" (p. 326). This "cyclical hierarchy" demonstrates the complementarity of simultaneous and successive codings (Cummins & Das, 1978). "The units that are part of a successive code are themselves simultaneous codes at a lower level, and the successively coded units are the basis for the next higher level of simultaneous coding" (Das *et al*, 1994: 59). Such a conceptualisation of 'chunking' is consistent with Luria: "The organisation of a series to be memorised as a result of which a series of words, repeated several times, is gradually converted into a group and acquires the character of a single simultaneous system" (Luria, 1966b: 75). The importance of this ascending spiral arrangement for the assessment of individual differences is that "the difficulty of any level's coding for the individual determines the locus of that reader's attention to a given task, and thus the processing factor upon which the given task depends" (p. 326). Low ability on one or other of successive and simultaneous syntheses would cause a "bottleneck" for coding to proceed to higher levels. Kirby and Das (1990) even suggest that ability on successive synthesis can be interpreted as capacity of working memory, while ability on simultaneous synthesis can be interpreted as "the 'size' of the units that can be constructed in working memory" (p. 322). The authors do not consider how this analysis might apply to the undertaking of marker tests for simultaneous and successive factors. It should apply, however, in which case cross-application of coding processes would not compromise marker test scores providing that the marker tests require processing to a sufficiently high level to surpass the "bottleneck".

Although both coding dimensions are undertaken for all sensory modalities, marker test batteries have typically restricted measurement to one modality for each process; vision for simultaneous synthesis, and audiation for successive synthesis. This has been seen, apparently, as a preferred strategy to minimise cross-process interference. For example, matrices for copying or inversion are presented for only a brief time interval to prevent elemental seriation, while the stimulus items of digit and word span tests are read aloud to restrict visualisation. Such a restriction is consistent with Luria's warning of the difficulty of using visual items to measure successive synthesis (Luria, 1966:78). However, such restrictions only seek to minimise the cross-variance in afferent information processing, and do not necessarily address individual differences in the efferent behaviour necessary to make test responses.

The differences between the simultaneous/successive dichotomy and the arguably more popularised spatial/verbal dichotomy need also to be mentioned. First, as elaborated above, simultaneous synthesis, although of a quasi-spatial nature, is not restricted to information presented in exclusively spatial format. Nor is successive synthesis restricted to verbal information. Simultaneous synthesis is used in verbal tasks of a logical-grammatical nature, e.g., solving a cryptic crossword, and successive synthesis is used for spatial tasks such as dancing or viewing video-graphics. With respect to visual processing in particular, Paivio (1975) reports results of research into the relationship between memory and cognition.

The results are generally consistent with a dual coding approach according to which verbal and nonverbal information are represented and processed in functionally independent, though interconnected cognitive systems. One system, the imagery system, is presumably specialised for encoding, storing, organising, transforming, and retrieving information concerning concrete objects and events. ... The other (verbal) system is specialised for dealing with information involving discrete linguistic units and structures. Independence implies ... that the two systems can be independently accessed by relevant stimuli: the imagery system is activated more directly by perceptual objects or pictures than by linguistic stimuli, and conversely in the case of the verbal system. Interconnectedness simply means that nonverbal information can be transformed into verbal information, or vice versa (Paivio, 1975:635).

Green (1977) argues that Paivio's division of memory into visual imagery and verbal-associated imagery parallels the distinct functioning of simultaneous and successive synthesis at the mnestic level. Such a dichotomy has salience for school performance. Hunt *et al* (1976) found that primary school children used both forms of information processing in classroom tasks. However

it would appear that those students who are high on the successive factor do better in rote and semantic short-term retention than those who are low, but this high successive synthesis factor, unless in combination with a high simultaneous factor, loses its importance where long-term comprehension is involved. This would suggest that simultaneous synthesis plays a major role in the organisation of information over time (p. 6).

That is, there is a connection between ability on simultaneous synthesis and efficacy of long-term comprehension, including long-term memory, and ability on successive synthesis and capacity of working memory, as suggested by Kirby and Das (1990) above. The simultaneous/successive dichotomy, then, would seem to underpin other proposed dichotomies, and be better located within a defensible theoretical framework. There is evidence from several studies that scores on factors representing simultaneous and successive synthesis are stable individual difference variables. In an intervention study involving the teaching of simultaneous and successive processing strategies, Leasak, Hunt and Randhawa (1982) report no changes in these cognitive abilities of Grade 4 students, but an improvement in scores of reading and arithmetic. The authors suggests that this result indicates an increased use of simultaneous processing as a more efficient strategy without any changes to basic cognitive ability. Naglieri and Das (1988) suggest that an individual's "choice" of processes or preferred strategy depends on: the demands of the task; the person's habitual mode of solving that type of problem; the person's competence in each type of process; and, the person's knowledge base. To bring about such a strategy change, the intervention of some metacognitive or planning function would be required.

2.7 Psychometric operationalisation with three factors

The next stage of operationalising the Luria model was to incorporate the functioning of the third block. Luria found that lesions to the anterior cortex, the third functional block, while leaving perceptual intelligence or afferent processing unaffected, impaired the planning and execution of consequent action or efferent processing. As with the dichotomous model above, such syndromes can be operationalised, in this case, as executive synthesis which involves the more complex cognitive functions of strategy formation, motivation, and behavioural regulation through speech. At the tertiary zone, executive synthesis is responsible for complexity of task achievement and depth of interpretation, including "analysis of visual perception" (Luria, 1973: 217). Executive synthesis particularly affects the use of language. With written text, this functioning allows the reader "to synthesise its various components or to move from the external text to its deeper subtext. ... i.e., decoding its inner emotional sense" (Luria, 1982: 244).

The tertiary zone of the third unit can also be engaged in chunking with language. "There is every reason to agree with Vygotsky that thought is completed rather than embodied in speech and that the transition from thought into speech involves several stages" (Luria, 1982: 158). The fronto-temporal region is responsible for re-encoding initial thoughts into predicative forms suitable for utterances, i.e., for efferent successive processing. This "lies at the foundation of concept formation" (Luria, 1982: 118).

At the secondary level, executive synthesis controls the ability to switch from one area to another in order to recall related information (Luria, 1973). This has been operationalised through tests for selective attention such as Stroop-type tests and mixed digit/letter recall tests. Ransley (1981), in studies with young children, found evidence for a third factor which he interpreted as representing selective attention. His tests were of the Stroop interference type. The attention factor was orthogonal to both factors for simultaneous and successive syntheses. As canonical correlates, the three factors provided significant predictive variance of school tasks in language and mathematics. "Selective attention makes sense, both as a factor derived from Luria's work, and its relationship with school learning" (Ransley, 1981: 228). Tulloch (1981) and Walton (1983) found support for the three-factor model in studies of individual differences in mathematical abilities among primary and secondary school students respectively. Try (1984) successfully used this model to explain individual differences in aptitudes to a computer-managed instruction program.

Das and others, however, have conceptualised the representation of the third functional block somewhat differently. Ashman and Das (1980) and Das and Heemsbergen (1983) found evidence for a third factor which they labelled "planning". An individual uses planning processes "to analyse a task, develop a means of solving the problem, evaluate the effectiveness of the solution, modify the plan as needed, and demonstrate some efficient and systematic approach to problem-solving" (Naglieri, 1989: 198).

In a complex task this planning factor would subsume other functions of executive synthesis such as the integration of the two dimensions of information encoding. The planning factor would seem to represent functioning in the tertiary zones of the third functional block rather than the secondary zones as represented by the marker tests typically used for executive synthesis. Reported marker tests for planning include trail making and pictorial search. The trail making task "is to connect, using a pencil, a series of boxes in correct sequence as quickly as possible" (Snart, Das & Mensink, 1988). This task seems in accord with the successive synthesis of efferent behaviour Luria describes as characteristic of the functioning of the third block. Snart, Das and Mensink (1988) found that planning was a significant discriminator between normals with higher than average IQ and children with higher than average IQ who also exhibited learning disabilities, particularly in literacy. Naglieri, Das and Jarman (1990) report that planning became increasingly more highly correlated with overall school achievement over grades 2, 6, and 10, and on mathematics and reading correlated as significantly as simultaneous and successive syntheses combined. "This suggests that the exclusion of planning from current intelligence tests is an important omission" (p. 433).

Knowledge base as a factor in the assessment of intelligence has also been of concern (Kirby & Das, 1990). For Luria, and his mentor Vygotsky, it was axiomatic that learning, i.e., the development of thought and language, is a function of social context. As executive synthesis has a superordinate role over the perceptual and coding processes, it might be expected that this factor could be sensitive to individual differences in socialisation. Clearly this would depend on the type of marker tests employed. Crawford (1986) studied the relationships between cognitive abilities, socialisation, and intellectual activity in the classroom. Factor analysis of test data produced three orthogonal factors, simultaneous, successive and executive synthesis. Significant gender and socio-economic differences were found in simultaneous synthesis, not executive synthesis. This suggested the possibility that simultaneous synthesis may be mutable, and that prolonged qualitative and quantitative differences in social interaction affect its development.

This issue was central to a comparative study of Aboriginal and non-Aboriginal Australian children by Klich (1983) (see also Klich & Davidson, 1984) using the Luria model. The authors point out that a process interpretation raises issues of the use of cognitive strategies and contextual appropriateness. Posttest questioning of children revealed a variety of strategies employed on each test that were not necessarily similar on all tests within a particular factor. Overall the contention that basic cognitive processes are culturally invariant was supported. Within such a framework individual and cultural differences impinge on cognitive strategies such as coding and rehearsal. Within the three factor model this requires differential interactions between the executive and the simultaneous and successive functionings.

This suggestion is supported by Crawford (1986) who argues that, while individual differences in abilities on simultaneous synthesis could account for why some children require less or more exposure to attain high levels of accuracy on any particular task, it is the self regulatory role of executive synthesis that importantly is also required for simultaneous processing to function at all. This view has further support from McCallum, Merritt, Dickson, Oehler-Stinnett and Spencer (1988) who report a study comparing a group of average-ability children matched on mental age with a group of educable mentally retarded (EMR) children. The results indicate that for EMR children planning and coding abilities are "relatively interdependent". "Apparently mentally retarded individuals are unlikely to exhibit planning deficits in the absence of processing deficits" (p. 409), although the authors consider an alternate explanation that Unit 2 abilities can be depressed by Unit 3 deficits due to neurological immaturity.

2.8 Psychometric operationalisation with four factors

Naglieri and Das (Naglieri, 1989; Naglieri & Das, 1990; Naglieri, Das & Jarman, 1990; Kirby & Das, 1990) have expanded the three factor model with the addition of marker tests for the first functional unit. This factor is labelled "arousal" or "attention". The model is referred to as the Planning-Attention-Simultaneous-Successive (PASS) model. The authors have argued for its adoption for assessment of intelligence in school contexts.

The extent to which the addition of a fourth factor improves the model needs to be examined. In the PASS model, attention is theorised as representing only the functioning of the first functional unit. It would follow that attention in this model is general rather than specific. However, the marker sub-tests for attention include instruments for both selective (picture matching) and sustained attention (word signals) (Snart, Das & Mensink, 1988). In fact, Kirby and Das (1990) describe both types of attentional functioning as being determined by the first functional block (p. 321). This seems at odds with Luria's conceptualisation where specific attention is a function of the anterior cortical block. "A wealth of information ... of *the higher forms of attention* is given by clinical studies of patients with frontal lobe lesions" (Luria, 1973: 274) (his emphasis). Furthermore, Luria (1973, Ch. 10) argues for Vygotsky's position that the specific orienting reflex is a product of social conditioning early in life. Posner and Petersen (1990) review more recent neurological evidence for three independent systems of attention: orienting, target detection (selective attention) and alerting (sustained attention). Difficulties with alertness can result from lesions to the right frontal lobes whereas targeting is a function of the "posterior attention system" (p. 30). This evidence could support an extended factor model, but with different functional units from Luria.

There is support for a four factor model in the literature. Klich and Davidson (1984) report factors for attention <u>and</u> planning in their study with Aboriginal children above. Naglieri, Das and Jarman (1990) report studies of exceptional children, in which a four factor model was employed. All sub-groups but one, delinquent children, were deficient on both attention and planning. The authors note that "planning and attentional deficiencies should vary consistently because of the close relationship between the first and third functional units. This close relationship is evidenced in factorial studies ... and the close anatomical connections described by Luria" (p. 435).

This "close relationship" could be explained by the inclusion of selective attention tasks which, being the responsibility of the secondary zones of the third functional block, should vary with the processing ability of the tertiary zone. Whereas the inclusion of a factor to represent the first functional unit seems commendable on grounds of theoretical completeness, the manner in which this has been carried out in the PASS model may require some further review. Das, Naglieri and Kirby (1994) emphasise the strong interrelationship between the first and third functional blocks on matters of attention.

> *It is clear from the review of both central and autonomic changes that accompany attention that the frontal lobes and the limbic system play an equally important role. The frontal lobes play a more important role in the mobilisation of attentional resources in voluntary attention* (p. 43).

This suggests, ironically, that operationalising separate roles for the third functional block presents a challenge to the validity of such tests. Consequently, in this research program the more parsimonious three factor model is employed.

2.9 Psychometric operationalisation in a computer adaptive format

Whether a two, three or four factor psychometric model is employed, interactions or overlap between the information processing syndromes impose a limitation on its explanatory power. Subjects with low ability on executive synthesis could show poor performance on simultaneous and/or successive synthesis due to the efferent processing demands of the testing tasks. Such a limitation is noted by Fitzgerald (1990). In response, Fitzgerald, Fraser and Fitzgerald (1995) have developed the battery for the three factor model into a computer-based adaptive format. All tests are to be undertaken under timed conditions. The battery includes: *Inverted Shapes Test* and *Paper Folding Test* as marker tests for simultaneous synthesis; *Word Recall Test* and *Number*

Recall Test as marker tests for successive synthesis; and, *Letter-Number Attention Test* and *Size Attention Test* as Stroop-type marker tests for executive synthesis.

One objective of using a computer format, particularly the graphics, is to provide instruments whose measures will produce minimal co-factor correlations. Another objective is to considerably reduce the number of test items of each instrument by employing an adaptive approach to item selection. As such, this computer format is ideal for individual testing. It could also be a suitable vehicle for research which examines how closely the psychometric model follows Luria's neuropsychology by using it to test patients with similar syndromes to those described by Luria. [More details of this instrument are not yet available for publication due to the terms of a commercial development agreement.]

In a review of the use of computers for assessment and intervention in psychiatry and psychology Burnett (1989) raises a number of issues pertaining to the reliability and validity of computer-based testing, and offers several criteria for evaluation of computer-based test interpretation (CBTI). Issues to be considered include:

> *(1) the degree to which psychometric test scores obtained using computerised and conventional test administration are equivalent;*
> *(2) whether the people being tested on computerised and conventional tests have an equivalent experience; and,*
> *(3) whether it is justifiable to interpret scores obtained from computerised test administration on norms established using the conventional methods* (p. 781).

Burnett concludes that in general the research evidence shows positive correlations between test scores obtained with conventional and computer formats. Subjects found computerised tests "to be more comfortable, more interesting, less difficult, and quicker to complete" (p. 781) than paper and pencil format. Recommendations for the design of CBTI systems include: predictor variables should be checked for adequate reliability; predictions should consider whether the subject being assessed has similar characteristics to the population used in establishing the prediction rule; interpretation should include a built-in capacity to adjust prediction rules to accommodate data from different base populations; and, the confidence interval associated with each predictive statement should be reported. In general, these criteria have been addressed in the development of the Fitzgerald *et al* computer adaptive battery.

2.10 Relationships to other models of individual differences

Of the many other approaches to modeling cognition and individual differences, those of general intelligence and cognitive style each deserve comment. Spearman's 'g' or general intelligence is a uni-dimensional concept of mental abilities (Benjafield, 1992; Rensick, 1976). Although general intelligence is a popular theory, even among teachers, Kirby and Das (1990) cite a number of commentators who found 'g' to be "an uninteresting concept" (p. 324). Representing intelligence by a single measure either denies the abundant evidence that cognitive abilities are multi-dimensional, or reduces measures of such multi-dimensionality to an average score, much as a single measure of "strength" might describe all of the variance in one's physical attributes (Howe, 1989). A single measure of intelligence does not inform about composition of that level of intelligence, and therefore is unhelpful in recommending appropriate educational intervention or pedagogic approach. Many current programs for academically able or "gifted" children, for example, suffer from such a shortcoming. Particularly where giftedness is measured by IQ only, school programs tend to be non specific and consequently unengaging and inappropriate (Gross, 1993). In contrast, the PASS battery can provide an assessment profile for giftedness which could be of assistance to instructional designers in that field (Karnes & McCallum, 1983). Schofield and Ashman (1987) report a study where the three-factor battery, along with the short form WISC-R, was administered to a large ($N = 323$) sample of primary school children. The subjects were grouped by IQ score: $IQ < 105$ as 'Below Average'; $105 < IQ < 124$ as 'Above Average'; and $IQ > 124$ as 'Gifted'. In addition, teacher nominations were accepted for inclusion into the 'Gifted' group. 'Gifted' children did not show differences on successive synthesis from the 'Above Average' group, but the 'Gifted' group did have superior scores on simultaneous synthesis and planning. The authors note that as "simultaneous processing is a more powerful discriminator of cognitive maturity than successive processing" (p. 18), and that since planning as measured in the study is a higher level metacognitive function, "the cognitive competence of gifted children resembles adult information processes more closely than that of their age peers" (p. 19). The performance differences between gifted and average children are both qualitative and quantitative, a point frequently referred to in the literature concerning gifted children (e.g., Gross, 1993).

The concept of general intelligence has not, however, "become as dead as the dodo, and belongs only to history" (Howe, 1989: 358). In a review article, Carroll (1992) reports a meta-exploratory-factor analysis of 460 data sets from the factor-analytic literature. Carroll proposes "a three-stratum model comprising a single g factor at the apex ... ; a series of broad abilities at the second stratum ... ; and a large set of narrow abilities at the lowest stratum" (p. 268). Carroll's meta-model is consistent with Luria under the following mapping: third stratum - anterior cortical functioning; second stratum - posterior cortical functioning, tertiary zone; first stratum - posterior cortical functioning, secondary zone.

With such a relationship, the Luria model can be used to interpret the results of other studies of general intelligence. For example, Guenther (1991) reports apparently contradictory evidence in a study of generic vs. specialised information processing using verbal and spatial tasks. The results of one experiment suggested specialised processing, whereas the results of another experiment suggested generic. Such a result can be explained by the Luria model, where information processing becomes less domain-specific as it ascends the zonal hierarchy. In Guenther's study, the verbal and spatial tasks of Experiment I required processing by successive and simultaneous synthesis in the primary zones, whereas the Experiment II tasks were of a higher order.

The Kaufman Assessment Battery for Children (K-ABC) (Kaufman & Kaufman, 1983) employs sub-tests to measure simultaneous and successive syntheses, as well as school achievement. In reporting a composite score as a measure of general ability, this approach attempts to use processing dimensions while retaining the notion of 'g'. Kirby and Das (1990) criticise the K-ABC on three grounds. First, the simultaneous and successive components are conceptualised in a lateralisation framework which is not derived from Luria's work. Second, tests for planning are not included in the K-ABC battery, and thus it is practically impoverished. Third, summing scores of independent components "attempts to satisfy both traditional and cognitive approaches to intelligence, and succeeds in satisfying neither" (p. 328). Naglieri, Das and Jarman (1990) argue that, "because the K-ABC was originally framed in relation to a reinterpretation of the WISC-R factors ... the K-ABC measures essentially the same factors as the WISC-R" (p. 424). These authors go on to demonstrate that these factors are similar to those of other general intelligence batteries.

A selection of sub-tests from the K-ABC was used, along with other tasks, by Cowart and McCallum (1988) in a multi-trait multi-method investigation of the PASS model. Their results did not support the PASS model on several grounds, including: limited discriminent and convergent validity; confounding of the simultaneous-successive dichotomy with visual-verbal; and non uni-dimensionality of the sub-tests. Cowart and McCallum conclude that use of the PASS model for assessment and intervention was premature. In their response Naglieri and Das (1990) point out *inter alia* that Cowart and McCallum used tasks which had not been included in PASS batteries before, and therefore lacked any established measures of reliability, or had used K-ABC tasks which characteristically had low reported levels of reliability. With the use of unreliable marker tests, the conclusions of Cowart and McCallum, Naglieri and Das argue, are unsurprising as well as invalid. In a factor study of the K-ABC by Das, Mensink and Janzen (1990), orthogonal factors for simultaneous and sequential processing were recovered, a new test of verbal simultaneous processing loaded heavily on to the K-ABC factor for simultaneous processing, while an additional planning factor with loadings from new tests for planning emerged. As this factor structure remained after the extraction of a factor for general intelligence, the authors conclude that the K-ABC would be strengthened by the inclusion of tests for planning, and that the Luria model factor structure exists "apart from a general or common factor of intelligence" (p. 10).

The relationship of Luria model factors with general intelligence was also studied by Boyd and Hooper (1993) who predicted WISC-R Verbal, Performance and Total IQ scores from the Luria-Nebraska Neuropsychological Battery (LNNB). Correlations reached significance on Verbal and Total IQs. These results differ from those of an earlier study by Cummins and Das (1978) in which successive synthesis was negatively correlated with WISC-R Verbal IQ and simultaneous synthesis was positively correlated with Performance IQ. In the Boyd and Hooper (1993) study, prediction of broad-band classifications were poor for the lowest (IQ < 70) and highest (IQ >

114) bands. The authors assume intelligence as a concept properly measured by IQ, and consequently warn users against the use of the LNNB for intellectual evaluation. In contrast, Geake (1994) argues that for above average children, unidimensional IQ scores fail to reflect asynchronous cognitive development, and that the Luria model, operationalised for psychological settings, provides a superior means of assessment of individual differences in cognitive abilities.

Karras, Newlin, Franzen, Golden, Wilkening, Rothermel and Tramontana (1987) used factor analysis to reinterpret the LNNB-C and compare the LNNB with other measures of cognitive functioning. Eleven factors are interpreted as representing academic achievement, spatial integration, kinaesthetic perception, motor speed, visuospatial analysis, rhythmic attention, somatosensory functioning, and four factors of verbal thinking. The authors note that this analysis "did not support the presence of pure simultaneous and successive abilities underlying neuropsychological functioning as measured by the LNNB-C" (p. 27). Nor did any of these factors readily compare with the Simultaneous Processing and Successive Processing factors of the K-ABC. The authors conclude that the LNNB-C may be measuring a more diverse range of neuropsychological skills than other instruments.

Other approaches which employ a diverse range of independent components are those of learning style and cognitive style. Biggs and Kirby (1980) report an interaction of preferred learning styles with processing components. Students with high ability on successive synthesis and low ability on simultaneous synthesis regarded academic achievement as best achieved by rote or shallow learning, while students with high ability on simultaneous synthesis and low ability on successive synthesis regarded academic achievement in terms of meaningful or deep learning. These findings are supported by Crawford (1986), who suggests that her finding that high scores on successive synthesis correlated with school assessment of maths achievement is possibly due to the classroom emphasis on algorithmic computational skills (shallow learning), and by Woodley (1994) who found that set manipulation reasoning tasks required simultaneous synthesis (deep learning).

However, possible associations of the functional organisation of the Luria model with the dimensions of cognitive style are not so clear. Cognitive style models typically use dichotomous constructs: field dependence - field independence, focussing - scanning, reflective - impulsive. For example, the construct of conceptual tempo which underpins the reflective - impulsive construct seems theoretically unrelated to measures of ability on either of the two Luria model encoding dimensions or the dimension of planning. Conceptual tempo could be related to the functioning of the first functional block, in which case some correlation with the Attention factor in the PASS model may be sought. It could also be noted that the third factor reported in Das and Jarman (1975) was labelled "speed".

The quasi-spatial conceptualisation of field independence - field dependence suggests that measures along that dimension may correlate with abilities on simultaneous synthesis. Cooper (1982) investigated individual differences in performance on visual comparison tasks. Two underlying strategies were identified: one which produced superior speeds for a "same" response and a constant additional time for a "different" response; the other produced an increasingly faster "different" response for increasing dissimilarity. Cooper labels the strategies "holistic" and "analytic" respectively. The holistic strategy processes spatial information as a whole: hence the constant "different" time. The analytic strategy processes information more sequentially: hence the increasingly shorter time to discover a difference as the number of differences increases. Cooper notes that these cognitive components did not correlate with either of the cognitive style dimensions of impulsivity - reflexivity or field dependence - field independence. Cooper's descriptions suggest that he unknowingly measured the application of simultaneous and successive syntheses to the task of visual comparison.

Benjafield (1992) describes Bruner's work with scanning - focussing. Bruner labelled subject scanning strategies as "simultaneous scanning" and "successive scanning". The experimental tasks required hypothesising and decision making, which could be theorised as functions of the third block. Benjafield also describes Bruner's concepts in terms of demands on working memory, similarly to the simultaneous - successive interpretation of Kirby and Das (1990).

Many cognitive style theorists invoke lateralisation for a neurological underpinning. Cochran and Wheatley (1982) investigated individual differences in spatial task-learning styles within a cognitive style framework. They note that high performers on spatial processing employ a holistic strategy over a verbal-analytic, and that such performance suggests right hemispheric preference. However, the authors note that "the relationship between strategy utilisation and hemispheric processing is not firmly established" (p. 14). Waber, Carlson, Mann, Merola and Moylan (1984) compared lateralised cognitive style variables between groups of children and from socioeconomically advantaged and disadvantaged backgrounds. Spatial processing stimuli were presented for contralateral response. The two groups showed significant differences in hemispheric asymmetry but not in overall task success. However, these authors also remark that the relationship between hemispheric function and cognitive style remains to be determined. Also it might be noted that Willis (1989) does not find such evidence for asymmetric afferent processing particularly persuasive.

It would seem, then, that lateralisation models do not afford unambiguous theory which can be readily operationalised. There may be a simple relationship between cognitive style attributes and Luria model factors, but the cognitive style approach seems, by comparison, to be conceptually shallow and confusing. The Luria model is operationalised from a more coherent and extensive theoretical basis and has far greater experimental validity and reliability, and hence better prospects for informing further understanding of individual differences in cognitive abilities.

Chapter summary

This chapter described Luria's neuropsychological model of information processing and its operationalisation into psychometric batteries for the assessment of individual differences in cognitive abilities. The model features three functional blocks associated with the sub-cortical, parieto-cortical and frontal areas of the brain. Sense data is hierarchically encoded within the second functional block by two independent syndromes, simultaneous and successive processing. Higher order cognitive functions are the responsibility of the third functional unit. Luria's descriptions of cerebral organisation were compared with evidence for the neurological organisation of music perception. It was then argued that the three-factor operationalisation of simultaneous, successive and executive syntheses as orthogonal dimensions best reflects Luria's descriptions of brain functioning. It was shown how other models of cognitive abilities can be understood in terms of the Luria model.