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Factors related to mechanical aptitude in Blacks I: Literature survey

Barbara I. Epstein

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SUMMARY

This report presents a selective review of theoretical and empirical research bearing on the structure of intelligence and the nature of mechanical aptitude relating to Whites and South African Blacks.

The report begins with a discussion of the nature of intelligence and classic factor-analytic work on intellectual structure. It examines models of intellect in Southern Africa, and the effects of culture and education in the differentiation of ability.

Research investigating the components of mechanical aptitude is surveyed and emphasis is laid on the nature of spatial factors and the difficulties which Blacks are thought to experience with depth perception.

The report culminates with a discussion into some background factors which might influence the development of mechanical aptitude in Blacks.

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OPSOMMING

Hierdie verslag bied 'n oorsig van teoretiese en empiriese navorsing t.o.v. die intelligensiestruktuur en meganiese aanleg van Blankes en Suid-Afrikaanse Swartes.

Die verslag begin met 'n bespreking van die aard van intelligensie en klassieke faktor-analitiese navorsing oor intelligensie-struktuur. Modelle van intelligensie in Suidelike Afrika word ondersoek, asook die effek van kultuur en opvoeding in die differensiasie van vermoëns.

Navorsing oor die komponente van meganiese aanleg word bespreek, en klem word gelê op die aard van ruimtelike faktore en die probleme wat Swartmense na bewering met dieptewaarneming het.

Die verslag eindig met 'n bespreking van enkele agtergrondfaktore wat moontlik die ontwikkeling van meganiese aanleg van Swartes beïnvloed.

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CHAPTER 1

INTRODUCTION

1.1 Purpose and Scope of the Report

The socio-economic progress of any country depends on a sufficient supply of trained labour. South Africa is a rapidly developing country with many large-scale engineering and building projects. In order to sustain such growth, essential manpower skills must be developed. Traditionally, South Africa has drawn its skilled workers from among the Whites, who constitute only 20% of the total population. According to manpower projections (Reynders, 1981; Sadie, 1981, 1982), however, there is a critical shortfall between the supply and demand of skilled labour, particularly in the mechanical and technical fields. Three times as many skilled blue-collar workers must be trained between now and the year 2000 as were trained in the period 1959 to 1979. However, Sadie (1982) has stressed that the number of economically active skilled Whites is at its maximum. The skills shortage will thus extend into the future and may put a brake on economic development. In order to reduce the severity of the bottleneck caused by the lack of skilled and trained manpower, and to ensure an adequate supply in the future, it is essential that the available labour pool be increased. Sadie (1981) has also stressed that it is the Blacks who will be required to meet South Africa's manpower requirements. Thus, massive efforts should be made to upgrade and train higher-level skilled Blacks. Recently, restraints barring Black workers from entering skilled jobs were relaxed (Bendix, 1979) which led to Blacks being admitted to technical courses, and in 1980 the first Black apprenticeship contracts were registered. Recognizing that South Africa will not be able to realize its development potential unless all population groups have equal opportunities to participate in the development process and be part of the high-level manpower resources of South Africa, the Government introduced the Manpower Training Act of 1981. This Act consolidates three previous Acts, the Apprenticeship Act of 1944; The Training of Artisans Act of 1951; and the In-Service Training Act, 1979. In terms of the Act, there is no differentiation between the training of employees of any race. Thus the importance of training for all has been recognized by the Government. In-Service Training schools and Black Technikons have been established, and tax-incentives provide encouragement to the private sector to institute training programmes.

There has been a marked increase in the population of Black pupils at higher educational levels and increasing numbers of young Blacks are matriculating (Reynders, 1981). It is estimated that by the year 2000, 68% of the matriculants will be Black (Van der Merwe, 1982). Although increasing numbers of more highly educated Blacks are becoming available to fill the manpower gap, several researchers ("Black prospects remain dim", 1981; De Lange, 1981; Morris, 1980) have commented on the poor quality of Black education, and others (Marcum, 1982; Verwey, Weiderman, & Wilkenson, 1983) have pointed to the alarming and disproportionally high drop-out rate for Blacks. Cloete (1981) has noted that integration of Blacks into the full labour market spectrum does not depend solely on the removal of legislation blockage, but also on the intentions of Blacks to enter all the available occupations. The vocational aspirations of Blacks in South Africa are notoriously unrealistic (Cloete, 1981; Erwee, 1981; Visser, 1978), and tend to focus on medical and social service careers, and minimal interest is expressed in the areas of the greatest need such as the practical, technical and mechanical spheres.

Until recently, most investigations into the intellectual structure of Blacks thus focussed on relatively uneducated Blacks performing relatively low level tasks, and very little research has been conducted in the mechanical aptitude of Blacks for occupations encompassing the whole engineering spectrum from artisan to engineer. A certain amount of prejudice exists, with many employers expressing the view that Blacks are slow in acquiring industrial skills, and that many, despite training and practice, do not reach the proficiency expected of Whites. They also assert that Blacks have poorly developed spatial depth perception and experience great difficulty in dealing with three-dimensional representation of information. These problems have been attributed to both genetic and cultural causes. In view of the prevailing stereotypes and the paucity of relevant information relating to the mechanical aptitude in Blacks, and in view of the projected manpower shortages in these spheres, it would seem particularly relevant to broaden the informational base relating to these skills which are necessary for attaining mechanical expertise, and to identify possible environmental variables which might promote the development of such skills. By so doing, it is hoped that some guidelines, albeit tentative ones, may be established which may have practical utility, not only in the selection and training of Blacks for technical posts, but also in the schools and in the wider community with regard to the fostering of activities which will promote mechanical aptitude.

CHAPTER 2

STRUCTURE OF INTELLIGENCE

2.1 Definition of intelligence

According to Sir Cyril Burt (1955) the concept of intelligence has its origins in intelligentsia, a word introduced by Cicero who endeavoured to provide a Latin terminology for Greek philosophy.

By the beginning of the twentieth century, three researchers who were to establish the foundations of modern psychology and have profound impacts on the subsequent investigations into human abilities had developed their most important concepts. Sir Francis Galton (1869, 1883), influenced by Darwin's (1859) theory of evolution had developed the statistical foundation for the study of individual differences, a central tenet of modern psychology; Alfred Binet (Binet & Simon, 1905) together with Henri Simon had developed the first objective and comprehensive scale to assess intelligence; and Charles Spearman (1904) had developed the statistical method of factor analysis and had formulated his theory of general intelligence.

At a symposium convened to investigate the nature of intelligence ("Intelligence and its measurement", 1921) the only point of reference that the psychologists appeared to hold in common was the different interpretations of intelligence offered by those attending the symposium.[1] These included the following:

- Terman: ability to carry on abstract thinking.
- Woodrow: the capacity to acquire capacity.
- Thorndike: the power of good responses from the point of view of truth and fact.
- Pintner: the ability to adapt adequately to relatively new relations in life.
- Dearborn: the capacity to learn or profit by experience.

Boring (1923) tautologically defined intelligence as being that which intelligence tests measure, and Spearman (1927, p. 14) aptly summed up the situation prevailing by commenting that "intelligence has become a mere vocal sound, a word with so many meanings that finally it has none".

Stoddard (1943) proposed a more comprehensive definition:

> Intelligence is the ability to undertake activities that are characterized by difficulty, complexity, abstractness, economy, adaptiveness to a goal, social value, emergence of originals, and to maintain such activities under conditions that demand a concentration of energy and a resistance to emotional ties. (p. 4)

Wechsler (1958) described intelligence as the

> ...global capacity of the individual to act purposefully, to think rationally, and to deal effectively with his environment. (p. 7)

Biesheuvel (1972) pointed out that intelligence is an ill-defined concept which changes its operational meaning with different tests and criteria. He proposed the term 'adaptability' as a concept which implies a response to a total situation, and

> ...as the capacity to gain insight into the nature of things and events, to grasp causal relations, to profit by experience and to acquire a number of skills whereby the adjustment between individual and environment is mediated. (p. 447)

Cottle and Downie (1970) divided definitions into two classes; those relating to abilities with regard to abstract thinking, manipulating symbols or learning verbal material; and those in which intelligence is viewed as the ability to adapt to the environment.

Butcher (1968) described a dilemma caused by adopting an 'open' approach to intelligence and acknowledging the effects of the environment (Biesheuvel, 1952a, 1952b; Vernon, 1965, 1966, 1969) which results in "intelligence as defined differing from intelligence measured by tests" (Butcher, 1968, p. 29).

He pointed out that psychologists have attempted to escape from the dilemma by either adopting an 'open' approach and distinguishing two kinds of intelligence (Cattell, 1963; Hebb, 1949) or they have adopted an operational definition, defining intelligence essentially in Boring's (1923) terms as what the tests test. Although acknowledging that both have their limitations, Butcher (1968) believed that

> In the long run, if this area of study is ever to form an integral part of scientific enquiry and to evolve beyond the status of quasi-science, the latter view must prevail and the loose 'open' concept be replaced, for experimental and statistical enquiries, by an agreed and measurable dimension or set of dimensions. (p. 36)

Lashley (1929) recognised that

> The concept of intelligence is becoming essentially a statistical one; it is the correlation between certain of the activities of the organism which are closely related among themselves and relatively independent of other activities. (p. 11)

This essentially is a description of the method of factor analysis which has played a major role in studies of the structure of human intellect, many of which will be referred to in the sections which follow.

2.2 Factor analytic approaches to intelligence

2.2.1 Aim of factor analysis

Pearson (1901), following an idea of Galton (1883), developed the product-moment correlation coefficient. This led to a major advance in the development of psychology as a quantitative discipline, when Spearman (1904, 1914, 1927), using concepts laid down by Pearson (1901), developed the statistical method of factor analysis and applied it to investigations into the structure of human intelligence.

The aim of factor analysis has been lucidly described by Harman (1967)

> The principal concern of factor analysis is the resolution of a set of variables linearly in terms of (usually) a small number of categories or 'factors': this resolution can be accomplished by the analysis of the correlations among the variables. A satisfactory solution will yield

> factors which convey all the essential information of the original set of variables. Thus the chief aim is to attain scientific parsimony or economy of description. (p. 4)

2.2.2 Spearman's two-factor model

One of the first theoretical expositions of intelligence was given by Spearman (1904, 1914, 1927) to account for the correlations observed between sensory tests and scholastic achievement. He proposed a two-factor hierarchical theory where a general factor, 'g', is common to performance on all mental tasks, but there are a number of specific factors, 's', which combine with 'g' to determine performance in each specific task area, and thus reflect the residual variance which is specific to that task. Spearman (1927) believed that 'g' depends on the general 'mental energy' of each individual, which is innate, and that the 's' factors represent the 'energies' through which 'g' becomes activated, and that these are affected by culture and training. J.M. Verster (1982), however, has maintained not only that Spearman's (1927) beliefs are unsubstantiated, but also that the concept of numerous 's' factors is unparsimonious.

Spearman (1904) postulated that activities can be ordered into a hierarchy based on their saturation with 'g', which he equated with the 'eduction of relations and correlates' which is the central mental function occurring in all cognitive activities.

The observation that Spearman's (1904, 1914, 1927) two-factor theory could not account for the results obtained in one of the earliest studies of mechanical aptitude, the Minnesota study (Paterson, Elliot, Anderson, Toops, & Heidbreder, 1930), led MacFarlane Smith (1964) to criticize severely Spearman's (1904, 1927) neglect of group factors. Indeed, a major criticism of his theory has been that it is not sufficiently complex to account for all results observed.

According to Vernon (1950), Spearman (1904, 1914, 1927) did not find group factors because his samples were not large enough. However, according to Wolfle (1940), Spearman always recognised the position of group factors. Whereas in his earlier work (1914, 1927), he accorded them minimal importance, in his later writing (1933) they play an increasing role. He thus recognised that the 's' factors are not independent and that certain broad group factors, such as verbal factors and spatial factors arise from the specific factors.

2.2.3 Hierarchical models of intellect

2.2.3.1 Burt's hierarchical model

Cyril Burt (1909, 1911, 1940, 1949) believed that Spearman's (1904, 1914, 1927) studies are not representative of all processes inherent in intelligence, and demonstrated that if the model is applied to a broad sample, it becomes necessary to reject the general factor hypothesis.

Burt's (1940, 1949) work was influenced by factor analytic studies (Alexander, 1935; Brown & Stephenson, 1933; El Koussy, 1935; Kelly, 1928) in which evidence for group factors is given. Burt's (1940, 1949) 'idealized' model (Guilford, 1967; Horn, 1972) conceptualized intelligence as being organised into a hierarchy consisting of successive dichotomies, each subdivision of a higher factor being further subdivided into two lower factors. At the head of the hierarchy is the general factor 'g', accounting for the major source of variance. After removal of the variance due to 'g', two major group factors, common to a wide range of performance are postulated, namely verbal-educational (v:ed) and spatial-mechanical (k:m) (Burt, 1940). These in turn are subdivided into minor group factors.

Burt's (1940, 1949) theory may be distinguished from that of Spearman (1904, 1914, 1927) in that in the former the existence of group factors between 'g' and the specific factors is acknowledged, while in the latter it is not. He viewed intelligence as being primarily genetically determined, and the development of the group factors as being related strongly to the maturational processes. Horn (1972) has made the point that Burt (1940) proposed the first major dichotomy between intellectual characteristics 'g' and 'practical' or behavioural characteristics, where 'practical' includes aspects such as psychomotor abilities and abilities for dealing with space and mechanical objects.

Burt's (1940) method of factor analysis allows only for orthogonal extraction (which does not allow correlation between the factors). J.M. Verster (1982) has pointed out that this precludes investigation of any possible relationships which might exist among various intellectual dimensions and thus imposes limitations and constraints on interpretation of data.

2.2.3.2 Vernon's hierarchical model

Vernon's (1950) hierarchical model of the structure of intellect probably represents best the British conception of intelligence. At the top of the hierarchy is a general factor 'g'. After removal of the variance due to 'g', whether by group factor technique or rotation of centroid factors, the positive residual correlations always fall into two main groups -- the verbal-educational group (v:ed) and the spatial-practical-mechanical group (k:m) (Vernon, 1950). The latter corresponds with Burt's (1940) spatial mechanical factor and includes minor group factors such as "perceptual, physical, and psychomotor, as well as spatial and mechanical factors" (Vernon, 1965, p. 725). The v:ed factor subdivides into verbal, numerical, and divergent factors. There are also various cross-links between the minor group factors. The minor group factors can be further subdivided into specific factors by further testing, but Vernon considered them to have little utility because of the narrowness of their range.

Vernon (1950, 1961, 1965) has a broader view than is evidenced in Burt's (1940, 1949) rather idealized hierarchy. He adopted Hebb's (1949) concept of a genetic component of intelligence which determines the biological potential for growth, which Hebb (1949) termed 'Intelligence A', and the interaction of this potential with the environment, which Hebb (1949) termed 'Intelligence B'. Hebb (1949) conceived of Intelligence A as being merely a theoretical construct, as its effects can only be observed in interaction with the environment which will determine the extent to which its potential is realized. Intelligence A is thus determined purely by maturational processes. Intelligence B, which Hebb (1949) defined in terms of accumulated knowledge and skills, is subject to maturation under environmental stimulation and can be measured as behaviour.

Vernon (1965) postulated, in addition to Hebb's (1949) dichotomy, a third kind of intelligence, Intelligence C, which refers to actual test results and thus provides an empirical estimate of Intelligence B. Vernon (1965) was aware of the difficulties and pitfalls in obtaining accurate measures of basic abilities and, in postulating Intelligence C, he was criticizing the view pervasive in the 1920s that scores on intelligence tests were regarded as absolute measures of innate capacities.

Vernon (1965, 1966, 1967, 1969) emphasized the important role of the environment in shaping the development of abilities and pointed out that 'g' is not determinate and innate as Spearman (1927) conceptualized it, but can "vary according to the particular measure" (Vernon, 1965, p. 766). This is in accordance with the theories of Ferguson (1954, 1956), Hebb (1949), and Hunt (1961).

2.2.3.3 Criticism of hierarchical model

Support for the hierarchical viewpoint was advanced by Eysenck (1979). He related the v:ed, k:m division to the differential functioning of the two hemispheres of the brain. The k:m factor (configurational, spatial, and synthetic) is related to right hemispheric functioning, whereas the v:ed factor (speech, calculation, and analytic activities) is related to left hemispheric functioning. According to Eysenck (1979) this provided biological support for the major theoretical divisions of cognitive ability. Factor analytic support for hierarchical concepts of general intelligence has also been provided by Eysenck (1979, p. 49).

Guilford (1967) criticized Vernon's (1951, 1965) and Burt's (1940, 1949) concepts of 'g' which are central to the hierarchical approach, and made the point that 'g' is not an invariant variable but depends largely on the particular test battery utilized. However, he later conceded that the weight of available evidence favours a hierarchical interpretation (Guilford, 1980). Other researchers have confirmed the weight of evidence favouring the hierarchical organization of intellectual structure (Cattell, 1971; Horn, 1976; Koestler, 1979; Sternberg, 1979; Wallbrown, Blaha, & Wherry, 1974).

Both Vernon (1950, 1965) and Burt (1940, 1949) were at pains to point out, however, that the hierarchical model is a means of classification only and is not representative of a unique univariant model of the mind. Vernon (1969) stressed that factor patterns are dependent on the tests used and on the nature of the groups being studied.

2.2.4 Thurstone's primary factor model

Thurstone's (1931, 1935, 1947) development of the statistical method of multiple factor analysis heralded a major turning point in psychometric theory, and drew attention away from the British school of thought, focussing it on America.

Thurstone (1931, 1935) proposed an alternative approach to the conception of 'g' and the concommitant hierarchical model. Several largely independent influences are operative in his empirical multiple factor model of intelligence, and he thus believed that not every mental ability is required in the performance of a mental task. Thurstone (1931) developed the centroid method of factor analysis to analyse the results of large batteries of tests into several common factors. The centroid method allows for one factor at a time to be extracted, each successive factor accounting for as much of the variance as possible. The first centroid factor thus has the highest loadings and each successive factor has smaller loadings. For a matrix of positive correlations the solution thus contains one general centroid with positive loadings and the remaining factors are bipolar (Harman, 1967).

Thurstone (1931) maintained that it is unreasonable to assume that an ability factor has a negative contribution to make toward performance. This would indicate that the more of an ability one has, the worse one would perform on a test. He thus proposed the principle of 'positive manifold', which rotates the axes in the factor space to a new position resulting in the elimination of all negative loadings in the final solution, except for those very small ones due to chance.

The criterion of 'simple structure' was developed by Thurstone (1947) to guide the investigator in carrying out the rotations of the factor axes to positions of greater scientific meaning. This was the first objective criterion for locating the axes in factor space. The principle of simple structure specifies that the axes must be rotated to maximize both positive and zero loadings and in this way achieve a parsimonious explanation of the factor solution. (The criteria for simple structure can be found in Thurstone, 1947, p. 335.) Rotations can be performed by keeping the axes orthogonal (factors are independent) or reducing the angle to obtain an oblique solution (factors are correlated).

Thurstone (1938) applied his method of multiple factor analysis to a sample of college students to whom he administered 56 tests. He identified nine factors, seven of which could be readily interpreted: verbal comprehension (V); word fluency (W); space (S); number (N); rote memory (M); perceptual speed (P); inductive reasoning (I).

Thurstone (1938) called his factors 'primary mental abilities' (PMA), and conceived of the factors as being functional and causal entities.

A larger scale study to replicate these findings was conducted using a sample of 710 eighth grade schoolchildren (Thurstone & Thurstone, 1941). They found that they had to deviate from orthogonality in order to achieve the two principles of positive manifold and simple structure. Ten factors were extracted which were rotated to an oblique simple structure. Thurstone and Thurstone (1941) have pointed out that it makes good sense both statistically and psychologically that abilities are correlated in some way. The initial seven PMAs of S, P, N, V, W, M, I were replicated, with minor variations being obtained in the patterns of the various age groups.

A second-order factor analysis was conducted on the six most stable primary factors (N, W, S, V, M, I) and a common general factor was extracted in which V and I had the highest loading and the M factor the lowest loading. The Thurstones (1941) likened this second-order factor to Spearman's (1904, 1927) 'g', and observed that the tests which Spearman had designed as the optimal measures of his 'g' appeared to be inductive in nature. In this way the seemingly disparate conceptions of intelligence held by the British and American theorists could be reconciled. The main differences between Thurstone's (1931, 1935, 1947) model of intellect and the earlier hierarchical model lie in his departure from the belief in the unidimensionality of intelligence, his methods of factor analysis, and his interpretation of factors.

2.2.5 Guilford's structure-of-intellect model

Research stimulated by Thurstone's (1931) factor analytic techniques resulted in a proliferation of haphazard studies in which the primary abilities were often narrower in scope. French (1951) for example, in his survey of 69 analyses, identified 59 factors, many of which were specific to the particular analysis. In an attempt to bring order into the chaos, Guilford (1956, 1967) formulated his structure-of-intellect model.

This model was the outcome of the extensive testing programme which Guilford undertook with the Army Air Force (Guilford, Fruchter & Zimmerman, 1952; Guilford & Lacy, 1947; Guilford & Zimmerman, 1947), where he found Thurstone's (1938) primary abilities insufficient to account for the observed relationships among the tests.

Guilford (1956, 1967) based his structure-of-intellect model on the view that there are three dimensions, the combinations of which determine different types of intellectual abilities. The first dimension refers to five kinds of 'mental operations' or basic psychological processes: cognition, memory, divergent production, convergent production, and evaluation. The second dimension refers to the four contents or 'areas of information' in which the operations are performed: figural, symbolic, semantic, and behavioural. The third dimension refers to six kinds of 'answers or products' that the subject is likely to produce: units, classes, relations, systems, transformations, and implications. The combinations of the three dimensions thus result in 120 different abilities each of which, according to Guilford (1967), represents a distinct factor.

When factor analytic techniques are applied, with the dimensions of the model being the frame of reference, support for many of the proposed factors is found, although not all the cells have been filled.

Eysenck (1979) has commented that the formulation of Guilford's (1956, 1967) model has allowed tests which might fit the vacant cells to be constructed, and has led to the discovery of new abilities.

Implicit in Guilford's (1967) theoretical standpoint is that these abilities represent actual causal independent entities. His factor analytic approach thus differs from Thurstone's (Thurstone & Thurstone, 1941) in that he rotates to an orthogonal structure, whereas Thurstone (Thurstone & Thurstone, 1941) allows an oblique rotation. Guilford (1956, 1967) has been sharply criticized for proliferating so many highly specific factors which cannot always be replicated and are often too trivial to have any practical utility (Horn, 1976; Humphreys, 1967; Hunt, 1961; McNemar, 1964; Vernon, 1965, 1969; J.M. Verster, 1982). Eysenck (1979), whilst stressing that Guilford's (1956, 1967) theory has heuristic value, has asserted that Guilford has confused dimensionality of test content with the dimensionality of human ability. J.M. Verster (1982) has commented that Guilford's insistence on orthogonality is at odds with the evidence from the literature in which significantly fewer, positively correlated ability factors are consistently suggested. Recently, however, Guilford (1980) has admitted that factors may be correlated to a certain extent.

Eysenck (1979) criticized Guilford, as did Horn (1972), Humphreys (1967), and Horn and Knapp (1973), raising the major objection that Guilford's claims to large numbers of factors are based on a Procrustes method of target rotations involving serious problems of subjectivity which might lead to arbitrary solutions. Whereas Guilford (1967, p. 55) admitted that any subjectivity is undesirable, he defended his standpoint on the grounds that "the facts of life in factor-analysis procedures are such that it is often necessary, otherwise strict adherence to the results of best simple structure may lead one astray psychologically".

2.2.6 Cattell's theory of crystallized and fluid ability

The hierarchical models of the British theorists and the multiple factor models of the American theorists are synthesized in Cattell's (1943, 1963, 1971) second-order factor model of fluid and crystallized intelligence (Butcher, 1968; Grant, 1969). His theory, based on correlated factors, attempts to reconcile the two points of view as 'g' might be obtained as a second-order factor among Thurstone's (1938) 'primary' factors.

Cattell (1943) argued that there is no single unitary 'g', but that there are two major co-operative cognitive factors: fluid intelligence 'g_f' and crystallized intelligence 'g_c'. Fluid intelligence is defined as "the measurable outcome of the influence of biological factors in intellectual development" (Horn & Cattell, 1966, p. 254), whereas crystallized intelligence is defined as "the principal manifestation of a unitariness in the influence of experiential-educative-acculturative influences" (Horn & Cattell, 1966, p. 254). Fluid intelligence is biologically determined and is thus a correlate of basic neural-physiological capacity. It is not a direct measure of innate potential in terms of Hebb's (1949) Intelligence A, but reflects rather adaptation to new situations and is comparatively free of cultural influences.

Crystallized intelligence on the other hand is more dependent on learned skills and habitual adaptations. It is thus determined by culture and education and represents habits which have become 'crystallized' as a result of earlier learning and represents the level of cognitive development attained through the accumulation of knowledge and skills. Whereas education has more of an effect on 'g_c' than 'g_f' learning affects both to some extent.

There are thus different characteristic relations between the two abilities with respect to age. Fluid intelligence 'g_f' rises more rapidly and reaches a maximum between the ages of 12 and 15, and starts declining from about the age of 22, whereas 'g_c' increases more gradually, reaching a maximum between the ages of 18 and 28 or beyond depending on the particular culture, and declines later with a minimal drop.

Cattell (1963, 1971) linked 'g_f' to a 'capacity to perceive relations and educe correlates' in Spearman's (1927) sense. However, while the 'g_f'/'g_c' distinction has some similarity to Ferguson's (1956) ability and learning set (Schepers, 1974) and to Hebb's (1949) Intelligence A and B, Cattell (1971) stressed that it should not be compared with Burt's (1949) and Vernon's (1950) distinction of v:ed and k:m, or to Guilford's (1967) convergent versus divergent thinking.

In order to test his theory, Cattell (1963) administered nine ability measures to a sample of 277 seventh grade boys and girls. Five tests of Thurstone's (1938) Primary Abilities (V, I, N, S and W) to measure culturally embedded abilities, and four subtests from Cattell's (1957) Institute of Personality and Ability Testing (IPAT) Culture Fair Intelligence Test (Perceptual Cues, Perceptual Classification, Matrices and Topology) together with a large number of non-ability variables constituted the test battery. S and W were considered to be less culturally saturated than the other PMAs and were thus likely to involve significant amounts of both 'g_f' and 'g_c'. Twenty-two primary factors were extracted and rotated to oblique simple structure. Two ability and four personality factors were extracted by means of a second order factor analysis.

The Culture Fair Tests and S loaded on the first factor as hypothesized and corresponded with the expected nature of 'g_f', while the remaining four PMAs (V, I, N, and W) and the perceptual series from IPAT loaded on the second factor, which thus corresponded with the expected nature of 'g_c'.

In a later study Horn and Cattell (1966) tested a more heterogeneous adult sample, using a variety of different tests and personality measures, to test the hypothesis that other influences affect intelligence. Three other second-order factors: general visualization ('g_v'), general fluency, and general speediness were predicted and the tests loaded on the factors as hypothesized. A fifth factor, general carefulness, was extracted. Horn and Cattell (1966) commented that from the analysis it is clear that visualization abilities "stand somewhat apart from the analytic reasoning and crystallized abilities of 'g_f' and 'g_c'" (p. 265) and that visualization is not as broad a concept as MacFarlane Smith (1964) conceived it to be. Other researchers (Cattell, 1967; Horn, 1976; Vernon, 1972) have confirmed this separation of 'g_v' from 'g_c' and 'g_f', which has a number of theoretical and practical implications.

Cattell's theory has been criticized extensively on statistical and methodological grounds (Grant, 1969; Guilford, 1980; Humphreys, 1967; Vernon, 1979). However, while J.M. Verster (1982) has assessed positively the weight of evidence in Cattell's favour, he has cautioned against accepting the theory as the valid representation of the structure of human ability.

2.2.7 Considerations with regard to choice of factor analytic methods

A fundamental difference between the American and British schools of thought is to be found in their conceptions of factors. Both Burt (1949) and Vernon (1965) stressed that the hierarchical structures are a means of classification only, and do not represent a unique and invariant model of the mind, whereas Thurstone (1938), Guilford (1967) and Cattell (1963) tended to view factors as causal entities and equated them with real abilities.

In the factor analytic method characteristic of the British psychologists, a general first-order factor is extracted followed by extraction of major group factors, and then minor factors. The loadings for 'g' are always positive, but the residual correlations are bipolar, that is, approximately half are positive and half are negative. They are thus rather difficult to interpret psychologically (Eysenck, 1979; Grant, 1969; J.M. Verster, 1982). Vernon (1965) criticized particularly the use by American theorists of selected homogeneous groups, such as students, where the range of 'g' is restricted. Accordingly, much of Vernon's (1965, 1966, 1967, 1969) work has been done on different cultural and educational groups and hence takes environmental contingencies into account. Both Vernon (1965) and McNemar (1964) viewed with disfavour the American multiple factorists' and, particularly, Guilford's (1956, 1967) "fragmentation of ability into more and more factors of less and less importance" (McNemar, 1964, p. 872), as they believed that this endless fractionisation of the mind tells us little about ability. Vernon (1965) commented, however, that whilst a "general intelligence factor seems unavoidable ... at the same time intelligence has many aspects which can be usefully represented, as Thurstone did, in terms of partially distinct overlapping primary factors" (Vernon, 1965, p. 724).

Whereas Thurstone's (1938) results seemed initially to be in direct opposition to the hierarchical model, his PMA model is not as irreconcilable with models relying on 'g' as might have been assumed. The two models have been demonstrated to be mathematically equivalent and are in effect reducible to one another (Bernyer, 1958; Cattell, 1963; Eysenck, 1979; Horn, 1972; Vernon, 1965). Indeed Vernon (1965) stressed that:

> It is just as legitimate to start, as it were, from the bottom upward -- that is to say, to extract the primaries -- and from their inter-correlations calculate the second-order factors, and if need be a third-order factor, corresponding to our major group factor and 'g'. (p. 726)

This interpretation, however, has not generally been accepted (Guilford, 1967, 1980). Grant (1969) believed that whereas the two models might be reducible to one another; if their philosophical, historical, and methodological points of departure are taken into account, then the two should be regarded as being widely disparate.

Cattell's (1943, 1963) theory is an attempt to bridge the gap between the two models. However, MacArthur (1973) noted that Vernon's (1950,

1965) and Cattell's (1943, 1963) models are not the same. Factors which are high in Vernon's (1950) hierarchy represent main common components which underlie a set of tests, while those lower in the hierarchy, all orthogonal, represent residual components. Factors high in Cattell's (1963) hierarchy, however, represent correlations among oblique factors lower down.

The first objective of factor analysis is "to attain scientific parsimony" (Harman, 1967, p. 4), in the pursuit of which a given matrix can be factored in an infinite number of ways. Harman (1967) and Wolfle (1940) made the point that this fact may not have been well known in the early days of factor analysis and hence this may have been the cause of many of the controversies between Spearman (1904, 1914) and Burt (1940) regarding the best or univariant solution.

Ultimately the choice of approach lies with the investigator. According to Harman (1967) the preferred type of factor solutions are determined on the basis of two general questions:

- statistical simplicity.
- psychological meaningfulness.

If the choice is made purely on statistical grounds, the approach would involve the representation of the original correlation matrix in terms of a number of factors, determined in sequence so that at each successive stage the factor would account for a maximum of the variance. This statistically optimal solution is the method of principal axes which was first proposed by Pearson (1901) and developed by Hotelling (1933). Another choice which Harman (1967) mentioned is the centroid solution, which approximates the solution of the principal axes.

If psychological meaningfulness is required, then the subjective judgement of the investigator is involved.

Considerable controversy reigns over whether to rotate blindly without knowledge of the variables represented by the data points or whether to rotate with knowledge. Comrey (1973) warned against the limitations inherent in adopting simple structure uncritically and rotating blindly as Cattell (1963) does, whereas Guilford (1967) on the other hand was strongly taken to task by Comrey (1973) for his subjectivity.

A warning note sounded by Kelly (1940) some 40 odd years ago still has relevance:

> There is no search for timeless, spaceless, populationless truth in factor analysis; rather it represents a single, straightforward problem of description in several dimensions of a definite group functioning in definite manners, and he who assumes to read more remote verities into the factorial outcome is certainly doomed to disappointment. (p. 120)

2.3 Models of intellect in Africa

2.3.1 Early research

One of the first factor analytic studies in Africa was the pioneering study conducted by MacDonald (1945). He administered a battery of 13 tests to a sample of 1 855 East African military recruits in order to obtain a small, valid selection battery. Three factors, which MacDonald (1945) did not interpret, were extracted using the centroid method of factor analysis. He did not rotate to simple structure. All the tests had large specificities, which indicates that only a small proportion of the variance was shared by the other tests.

A general factor was obtained in a study by Vernon (1950). He administered MacDonald's (1945) test battery to smaller samples of African recruits. Vernon (1950) also extracted three factors and discarded one which did not yield a logical grouping of tests. In accordance with his model, Vernon (1950) interpreted the first factor as general adaptability to an unfamiliar testing situation. He did not equate it with 'g', as formboards and a dexterity test also loaded on it. The second bipolar factor divided the tests into primarily cognitive factors which Vernon (1950) interpreted as being akin to 'g', and a manipulative/physical factor. In accordance with the British approach, the factor matrix was not rotated to simple structure.

No mention is made by MacDonald (1945) or Vernon (1950) of the level of formal schooling or the extent of urbanization of their samples, although Grant (1969) commented that considering the period when the information was collected, the sample was probably largely illiterate and rural. He also pointed out (Grant & Schepers, 1969) that most of the early factorial studies in Africa reported high specificities for many of the tests -- suggesting that had more tests been included, more factors could have been extracted, and the factors might have become clearer.

Research conducted by the National Institute for Personnel Research shortly after the Second World War led to the development of the General Adaptability Battery (GAB) (Biesheuvel, 1952a, 1954) designed as a general screening device for the gold mining industry.

Biesheuvel (1954) factor analysed the scores obtained on the GAB of a group of mineworkers and of a group of motor assembly operators. In both cases an unrotated solution yielded a general factor 'g' on which all tests had substantial loadings and which accounted for 45% of the variance, and a doublet for two sorting tests. The highest loadings obtained were for formboards and Koh's Blocks. Although Biesheuvel (1954) interpreted 'g' as practical general intelligence, Grant (1969) criticized this concept of 'g' and attributed it to being a function of the tests used. M.A. Verster (1976), however, made the point that Biesheuvel's (1954) study was not intended to be a theoretical statement on the structure of African intellect, and therefore should not be interpreted as such. The results obtained were dependent on the tests which were selected to fulfil a particular purpose.

The factor structures extracted by MacDonald (1945) and Biesheuvel (1954) are similar, and were attributed by Irvine (1969a) to "the emphasis on performance of culturally alien tasks by unselected populations which produces general factors and others with variance specific to the nature of the tests themselves" (p. 26).

Murray (1956) administered a battery of 19 performance tests to 119 African industrial workers. During the factor analysis, three factors were extracted of which only one was considered significant for interpretation. Murray (1956) then concluded in a rather sweeping statement "that so far as the African is concerned the simplicity of the factor structure is determined by a simplicity of mental structure" (p. 63). This rather simplistic interpretation has been extensively criticized, particularly on the grounds that he did not administer a comprehensive battery of tests (Grant, 1969; Kendall, 1971, 1980; M.A. Verster, 1976) which in itself could possibly have precluded the emergence of additional factors.

In a well designed study, Brimble (1963) compiled a carefully selected test battery for a more homogeneous and restricted sample than had previously been used. He administered his battery to 419 Rhodesian schoolboys. Two factors were extracted, one of which accounted for 86% of the common variance which Brimble (1963) interpreted as 'general ability' (although he recognized that test adaptability might be involved). The second factor was considered to be mainly abstract reasoning with elements of spatial perception included.

Irvine (1962, 1963) conducted extensive surveys in Zambia and Rhodesia on varied Black samples: Standard 6 schoolboys in Rhodesia and Zambia; male students in a Mine Youth Training Camp who could not obtain secondary school places; Standard 8 pupils in Zambia and Kenya; Black and White Kenyan boys of African, American and British origin in Standards 7, 8 and 9. Factor analyses were performed using Hotelling's (1933) Principal Components Analysis and Kaiser's (1958) Varimax criterion for orthogonal rotation. Four factors were extracted in all four samples. The factor analyses showed stability of the major cognitive dimensions of 'g' (which Irvine, 1969a, interpreted as reasoning); v:ed (second language verbal skills), and n:ed (numerical skills) over all samples. Perceptual factors, although present, were not common to all the samples, possibly because they were not particularly well represented in the test batteries.

The tests of overlearned skills were factorially very stable, which led Irvine (1969a) to comment on the changes in test performance in non-verbal skills which have been obtained in Africa as a result of coaching (Horn, 1976; Lloyd & Pigeon, 1961). He concluded furthermore that overlearned constructs are more stable across cultural groups than those from figural tests.

Irvine (1969a) concluded that factor analysis methods could thus be used, albeit with caution, for analysing results from non-Western cultures and that constructs could be applied across cultures in Africa.

From Irvine's studies it is apparent that the better educated groups yield more factors than the less educated or illiterate groups. Grant (1969) made the point that since Irvine's samples were literate they could cope with pencil and paper tests, and thus a more diverse test battery could be assembled, whereas researchers of less educated and unacculturated groups are limited to using performance tests only.

2.3.2 Later studies

Grant and Schepers (1969) believed that the concept of general adaptability prevalent at the time they were writing was largely a function of the theory of test development in operation. All the studies used British factor analytic techniques and thus the factor matrices were not rotated to simple structure, and the early researchers thus accepted a finding of one general factor. There were also only very limited numbers of tests available for use with illiterate and semi-literate Blacks. Grant and Schepers (1969) accordingly suggested an alternative explanation for the factor composition of the MacDonald (1945) battery. They rotated Vernon's (1950) factor matrix to simple structure and obtained two factors which they interpreted as 'eduction of relations' and a dexterity factor. This confirmed their hypothesis that a multifactorial structure could be identified in an African population.

In an attempt to verify this conclusion, they administered five new cognitive tests (Form Series Test, Circles, Form Perception, Fret Repetition, and Fret Continuation) together with the GAB to a sample of 90 male African mine recruits. The data were subjected to a principal factor analysis and two factors were extracted using

Kaiser's (1958) criterion, and an orthogonal rotation to positive manifold was conducted. They interpreted the first factor as 'eduction of relations' (Fret Repetition, Circles, Koh's Blocks, Fret Continuation, Form Series Test, Sorting II, and Cube Construction), as all the tests "involve the reproduction of given patterns and both analysis and synthesis are required" (Grant & Schepers, 1969, p. 190), which is similar to MacDonald's (1945) first factor. The second factor was interpreted as 'speed of perception' (Sorting I, Sorting II, Cube Construction, Tripod, and Form Perception) as all the tests "involve the sorting of objects under speeded conditions" (Grant & Schepers, 1969, p. 190).

Grant (1969) later suggested 'perceptual analysis' as a more appropriate label than 'eduction of relations' which he thought might be confused with 'g'.

Grant and Schepers (1969) made the point that both the Form Series Test and the Form Perception Test had a large proportion of specific variance unaccounted for. They, therefore, proposed extending the battery to overdetermine the dimensions defined by the two tests, and hypothesized that a four-factor solution might be the outcome.

Accordingly Grant (1970a, 1972) conducted a series of studies to overdetermine the dimensions of conceptual reasoning, defined by the large specificity ($\underline{s}^2$ = 0,68) of the Form Series Test; and spatial perception, defined by the specificity ($\underline{s}^2$ = 0,55) of the Form Perception Test.

To overdetermine the dimensions represented by the Form Perception Test, Grant (1970a) administered four spatial tests and the GAB to 100 African mineworkers. A principal factor analysis yielded a two-factor structure: 'perceptual speed', (which had been found in the Grant and Schepers, 1969, study), and 'perception of form relations'. This study will be discussed in more detail later (see section 3.3.2).

In Grant's (1969, 1972) studies to overdetermine dimensions of conceptual reasoning, he administered the General Adaptability Battery and four tests, purporting to measure conceptual reasoning, to 100 African mineworkers. The matrix of intercorrelations was subjected to a principal factor analysis, and orthogonal rotation to a fairly simple structure and positive manifold was carried out. Two factors were extracted: 'conceptual reasoning' and 'space'. All the tests loaded on 'space', which led Grant (1972) to hypothesize that had an oblique rotation been performed, the two factors would be correlated to the extent of 0,60. The test having the highest loading on the conceptual reasoning dimension was the Form Series Test. Kendall's (1971) observations that high correlations between the tests and education were related to high loadings on the conceptual reasoning factor (which was not the case with the space factor) led him to hypothesize that conceptual reasoning is a highly adaptive ability in Africans striving to meet the demands of a Western technological society.

Grant (1972) defined conceptual reasoning as the ability to discover or apply a rule by relating concepts to one another. In a study of a Venda group in cultural transition, Grant (1969) administered an extended battery of tests to 417 Venda males to account for five postulated dimensions of African intellect: perception of form relations, perceptual analysis, conceptual reasoning, perceptual speed, and space. Although the five hypothesized factors were extracted, T. Taylor (1977) has suggested that as many of the factors are doublets and many are correlated, Grant (1969) overfactored the data, while M.A. Verster (1976) has commented that the factors are ambiguous and not clearly defined.

In a follow-up study of a Pedi group in cultural transition by Kendall (1971), in which a slightly modified test battery was used, the four factors of perceptual analysis, conceptual reasoning, perceptual speed, and space were extracted.

2.3.3 Limitations of early intelligence tests for Blacks

Much of the early research in Africa on the structure of intelligence in African Blacks was hampered by a number of problems, which appear to account to a large extent for the rather undifferentiated intellectual structure uncovered, and the resultant lack of support for the models of intellect proposed by the Americans. Because of the numerous difficulties involved in applying Western concepts and Western tests to illiterate and semi-literate Black people in Southern Africa, the researchers had to make do with relatively few performance type tests in their studies which could not thus sample the whole domain of intellectual functioning.

The paramount role of education has also been illustrated in the studies by Irvine (1962, 1963, 1969a) who found that when higher-educated Blacks are tested, their intellectual structure becomes more differentiated. Grant (1969) also illustrates in his study that education affects not only the mean level of performance, but also the structure of intellect. The lack of support for a more differentiated model of intellect which would fit the patterns advocated by the American school may thus be ascribed to the particular stage of development of the populations which were tested. As Irvine (1969a) commented:

> The earlier, and possibly continuing controversies over the nature of theoretical frames for cognitive structure ... have largely arisen out of the nature of the tests used and the populations to which they have been administered. African results tend to underline the relativity of human experience, and absolute theoretical constructs may require modification if psychological advances are to be made. (p. 27)

2.4 Differentiation of ability

2.4.1 Ferguson's theory

A theory which would appear to have relevance for the findings which emerged from the factor analytic studies of African intellect to account for the development and differentiation of various cognitive abilities in terms of learning is that of Ferguson (1954, 1956).

Ferguson (1956) defined 'ability' in three ways, namely: as a measure of performance in a task; as a factor score obtained from factor analysis; and as an attribute (which is subject to modification by environmental and genetic factors) of the state of the organism. He did not see any basic incompatibility between these definitions and suggested that they describe much the same construct.

In Ferguson's (1956) terms, abilities are attributes of behaviour which have become overlearned to the extent that they become invariant through repeated practice and learning. In terms of learning theory, an ability is thus an overlearned acquisition which has reached an asymptote. As the individual's intellectual organization becomes more complex as a result of maturation and cultural demands, specific skills designed to cope with a unique set of functionally related tasks become differentiated. Eventually through practice these in turn start crystallizing until they become relatively invariant new abilities, which can be applied to the performance of similar tasks.

Ferguson (1954) thus assigns a central role in the differentiation of ability both to the concept of transfer factors based on prior experience, and to factors arising which are specific to the new task. Transfer refers to changes in performance on one task as a result of practice on another. The change in performance may be either facilitated or inhibited depending on the skills which the individual has previously acquired.

Heinonen (1962), in a study to determine whether practice designed to improve performance in a certain task would transfer effects to performance in other tasks, found that the more similarity there is between two tasks, the more transfer is apparent. This might suggest, according to Guilford (1967), that if practice is in a task for a single factor, transfer is relatively limited within the performance related to that factor.

An implication from Ferguson's (1954, 1956) theory would be that practice in exercises related to those contained in tests measuring an ability should lead to increases in scores in those tests. A study by Blade and Watson (1955) illustrates the effect of taking engineering courses on the visualization abilities of first year engineering students. The observed increase in correlation between initial and final scores on a visualization test and final exam results in engineering drawing and descriptive geometry is an indication that the course might have brought the students closer to their asymptote for the visualization factor.

An individual will thus learn more readily those activities which are facilitated by prior overlearned acquisitions. As an adult has many abilities which are overlearned acquisitions, abilities which tend to facilitate one another will develop. This line of reasoning led Ferguson (1956) to suggest that the positive correlation between abilities might be accounted for by the operation of transfer, a concept which has some relevance for the methodology of factor analysis. He thus accounted for the correlations of many tests in terms of positive transfer, and for the differentiation of ability in terms of the learning process itself which has operated in such a way as to facilitate differentiation.

During the process of learning, abilities specific to the task itself emerge. At the beginning of the learning process, more variance is accounted for by prior acquisitions than by task specific factors; this position reverses during the course of the learning process. Ferguson (1956) does not himself offer any empirical evidence in support of his transfer theory, but cites research by Fleishman and Hempel (1954b) to support his contention. Other researchers (Fleishman, 1972; Fleishman & Hempel, 1956; Heinonen, 1962; Schepers, 1962) also showed that systematic changes occur at different stages of learning a complex psychomotor task, and of learning a complex conceptual task (Bunderson, 1967). Buss (1973) in a reinterpretation of Ferguson's (1954, 1956) model, attempted to place the relationships between learning, transfer, and abilities within a factor analytic model. He proposed a multivariate change model in which changes in cognitive structures (indicated by the individual's factor score) and in the task structures (indicated by the factor loadings) provide the theoretical basis for the process of transfer. Buss' (1973) model accommodates both the role of ability factors in the learning of a specific task and the role of learning in the acquisition of a factor.

Implicit in Ferguson's (1954, 1956) theory is the assumption that all learning (except for early learning) depends on prior acquisitions and on transfer. Ferguson (1954) does not, however, provide a clear explanation of how early childhood learning does in fact occur, although he does refer to Hebb's (1949) distinction between early and late learning. Hebb (1949) emphasized that the particular stage in life at which learning occurs would determine how effectively the individual learns. This in turn implies that lack of early experiences have a limiting effect on the development of new abilities in the adult with the result that

> ...if a child's environment is restricted with respect to certain activities he may function well below the limit of his potentiality in those activities at varying ages, and a permanent impairment at the adult stage may result. (Ferguson, 1954, p. 99)

This highlights the role of culture and education in the differentiation of ability and is particularly relevant for the study of African intellect. As Ferguson (1956) observed:

> Cultural factors prescribe what shall be learned and at what age; consequently different cultural environments lead to the development of different patterns of ability. Those abilities which are culturally valid, and correlate with numerous performances demanded by the culture are those that show a marked increment with age. (p. 121)

2.4.2 Effect of culture on the differentiation of ability

Many researchers have pointed to the effects of culture and environment on the patterning and differentiation of abilities (Cohen, 1969; Lesser, Fifer, & Clarke, 1965; Pick, 1980; Ramirez & Price-Williams, 1971; Stodolsky & Lesser, 1967) in countries as diverse as Newfoundland and Canada (Bowd, 1973; Burnett, 1955; MacArthur, 1968, 1973; Vernon, 1965, 1969); Central and East Africa (Irvine, 1969a; Jahoda, 1979); Southern Africa (Biesheuvel, 1952a; Crawford-Nutt, 1977a; MacArthur, 1973; Vernon, 1969); England (Vernon, 1969); America (Flaugher & Rock, 1972; Loehlin, Lindzey, & Spuhler, 1975; Michael, 1949) and China and South America (De Freis, Vandenberg, McClearn, Kuse, Wilson, Ashton, & Johnson, 1974).

Support for Ferguson's (1954, 1956) theory that environmental demands lead to the development of different ability patterns is given by Burnett (1955), who demonstrated that children reared in relatively isolated communities have impoverished verbal and reasoning abilities but well-developed perceptual and motor abilities compared with the pattern of abilities found in children reared in urban centres.

Both Vernon (1965, 1966, 1969) who stressed cultural influences, particularly socialization practice, and Irvine (1963, 1969a) maintained that the sources of variance obtained in factor structures relate to environmental factors, whereas MacArthur (1968, 1973) pointed directly to the role of ecological factors.

MacArthur's study in 1968 of White, Indian-Metis, and Eskimo groups in Canada, and his study in 1973 examining the patterning of cognitive abilities of adolescent Eskimos and Nsenga Zambians who had hunting and agricultural backgrounds respectively, provides further support for Ferguson's (1954, 1956) hypothesis. MacArthur obtained three oblique factors resembling 'g_f', 'g_c', and visualization ('g_v') for the Eskimos, and two factors for the Nsengas; 'g_f' merging with 'g_c' and a field independence factor which was narrower than 'g_v'. Following Witkin's (1967) and Berry's (1971a) differentiation theory, MacArthur (1973) suggested that the Canadian Eskimos' hunting ecology and upbringing which encourages independence, fosters not only a broad spatial and field independent cluster of abilities, but also a distinctive cluster of non-verbal and inductive reasoning abilities; whereas the Nsengas' agricultural ecology and upbringing, which stresses conformity, blurs the differentiation between the factors.

These studies all adhere to the hierarchical structure of intelligence. Whereas general and major group factors, similar to those found in the West, typically are extracted, specific factors differ markedly between cultures. Thus the pattern of abilities appears to stabilize over periods of time as a result of interaction with the environment, with cultural factors playing a major role in the formation of the structural pattern. The stabilization process appears to take the form of a hierarchical order with the abilities at the higher level least affected by the specific cultural demands (Hudson, 1967).

Working within the American framework, however, some psychologists have taken a different standpoint, and stressed the essential similarity of ability patterns across cultural and racial groups within Thurstone's (1938) PMA model (De Freis et al., 1974; Loehlin et al., 1975; Michael, 1949; Vance & Wallbrown, 1978; Vandenberg, 1967; Vandenberg & Hakstian, 1978). Indeed Vandenberg (1967) and Vance and Wallbrown (1978) argued that differences obtained in other studies could be accounted for in methodological terms, Vernon's (1969) use of environmental variables in the factor analysis being an example. Vandenberg and Hakstian (1978) reanalysed the data from Vernon's (1969) studies undertaken in four different cultures (Scottish, Ugandan, Canadian Eskimo, and Canadian Indian). Using a variety of statistical procedures, their results are indicative of a high degree of agreement in the factor definitions between the sample pairs. Interestingly, the factors themselves fitted more readily into Thurstone's (1938) PMA model than into Vernon's (1969) own hierarchical model. Jahoda's (1980a) opinion that much of the controversy over the nature and extent of the variation in mental abilities depends on the model assumed, appears thus to be confirmed.

Indeed, Irvine (1978) in a comprehensive survey of 91 factor analytic studies of intellectual structure across cultures found that despite the diversity of factor analytic methods, cultures sampled, and tests used, broad consistencies are apparent. The factors can be classified into six groups labelled as reasoning, verbal abilities and skills, spatial/perceptual processes, numerical operations, memory functions, and physical/ temperamental quickness. These factors are similar to Thurstone's (1938) original PMAs.

2.4.3 Effects of education on differentiation of ability

A frequently encountered finding in developing countries is that level of education facilitates performance in various tests of ability (Crawford-Nutt, 1977a, 1977b; Grant, 1969; Mauer, 1974; McFie, 1961; Schepers, 1974; Silvey, 1963; T. Taylor, 1977). This is because increasing exposure to education facilitates increasing psychological differentiation (Burt, 1954; Crawford-Nutt, 1977a, 1977b; Garrett, 1946; Grant, 1969; Guthrie, 1963; Hudson, Roberts, van Heerden, & Mbau, 1962; Irvine, 1962, 1963, 1969a; McFie, 1954, 1961; Vernon & Parry, 1949). Studies by McFie (1954, 1961) indicate that exposure to certain activities during formal training might stimulate the differentiation of mental abilities involved in the performance of these activities. McFie (1961) administered a battery of eight ability tests to a group of Ugandan technical trainees and retested them two years later when training was complete. McFie (1961) claimed that the general factor found in the early stages of training was reduced, other factors became more strongly defined and the correlations between test scores thus decreased on retesting. He hypothesized that the results might indicate a changing structure of intellect as a result of specialized intervening education. An examination of the intercorrelation matrices, however, indicates that this is only the case with some of the tests; on others a high correlation on retesting is observed. Deregowski (1972a) made the point that McFie's (1961) lack of a control group did not allow him to separate out maturational effects from the effects of the training.

Vernon (1950) found that the patterning of k:m abilities depends to a considerable extent on the experience and training of the testee. Differences were found among a group of inexperienced trainees and qualified engineers, and among women, adolescent boys, and adult males (Vernon & Parry, 1949). Vernon (1950) commented that "considerable growth in k:m occurs in average male adolescents ... probably accompanied by alteration of structure" (p. 120).

Irvine (1978) in his cross-cultural study, found that regardless of the number of variables on which the analyses were based, a correlation was found between level of education and the number of extracted factors.

Hudson et al. (1962) showed that ability patterns vary with different stages of learning. The more educated and skilled groups (6, 9, and 12 years of schooling) produce a different factorial structure from the least educated group (3 years of schooling).

Hudson's (1962) test battery thus tested different dimensions at the different levels; unskilled, semi-skilled, and skilled due to the factor structure of the task altering as learning proceeds (Ferguson, 1956). At low levels of skill and education, variance would be due to cultural differences (acculturation). This is particularly because schooling is an indication of familiarity with Western modes of thought (Bruner, 1966). Training and the impact of industrialization would thus lead to cultural differences becoming less pronounced and variance would be due more to individual differences.

A similar finding was noted by Crawford-Nutt (1977a, 1977b). He administered the Symco Test (Crawford-Nutt, 1974) to a large sample of mature Blacks at all levels of education and found that while the test correlated to some extent with general intellectual ability at low levels of education ($\underline{r}$ = 0,4, $\underline{p}$ < 0,005), it correlated to a lesser extent at the higher levels ($\underline{r}$ = 0,2, $\underline{p}$ < 0,05). This provides further support for Ferguson's (1954, 1956) theory, and led Crawford-Nutt (1977a, 1977b) to suggest that the rationale of the test changes with educational level.

At low levels of education, intellectual abilities are relatively undifferentiated and the testee draws on general ability. At higher levels, abilities become more clearly differentiated and the testee calls upon fewer but more specific abilities to solve problems pertaining to one specific test. French (1965) also commented that the same tests may measure different abilities for different groups of people. Biesheuvel's (1956) comment on the importance of education appears relevant:

> Scholastic education is the mechanism which establishes the mental skills through which intelligence can best make itself effective, and whereby the mind is raised to higher adaptive levels. (p. 448)

Grant (1969) hypothesized that in unacculturated groups, factors tend to be more unrelated than for the more acculturated groups, and that the emergence of 'g' is a result of the factors being so highly correlated that a single factor is obtained. As part of his (1969) studies of Venda groups in transition, he constructed an urbanization scale, and using that scale and length of schooling as classification variables, he isolated four groups, namely, rural or urban literate, and rural or urban illiterate. Grant (1969) concluded that schooling affects not only the level of performance but also the structure of intellect to a certain extent. An interesting point is that urbanization, while affecting the level of performance, did not affect the structure of intellect in Grant's (1969) samples.

Irvine (1969a, 1978) reported a more diversified factor structure. He also found that better educated groups yield more factors than the lower educated or illiterate groups. Grant (1969) made the point that this difference might be accounted for by the fact that Irvine (1969a) could assemble a more diverse test battery as his subjects were literate and could cope with pencil and paper tests, whereas studies with illiterates have had to make use of performance tests.

CHAPTER 3

MECHANICAL APTITUDE

3.1 The concept of mechanical aptitude

The term 'aptitude' refers to the ability of an individual to acquire certain behavioural patterns and skills, given the appropriate opportunity. Ability and aptitude are not synonymous. Any special ability, cognitive style, personality, motivation, or interest variable which shows a relation to learning should be considered as identifying aptitude.

There is a general belief among laymen that mechanical aptitude represents abilities which are distinctly different from other abilities. With this in mind it has not been uncommon to regard it as "little more than some form of finger dexterity associated with a willingness to get one's hands dirty" (Thurstone, 1951, p. 1). Thurstone (1949, 1950, 1951) suggested that mechanical aptitude resides mainly in the head, and encompasses a complex of distinct intellectual abilities. Other investigators (Bowd, 1973; French, 1951; Fruchter, 1952a; Guilford, Fruchter, & Zimmerman, 1952; Harrel, 1940; Patterson, 1956; Vernon, 1950; Wittenborn, 1945a, 1945b) have confirmed this. The construct of mechanical aptitude is thus assumed to consist of a set of interrelated skills, abilities, and characteristics, which enable a person to achieve superior performance on mechanical tasks (Thurstone, 1949); the three most important being visualization, perceptual, and mechanical information and experience (French, 1951; Super, 1949).

Nunnally (1970) asserted that the abilities which constitute mechanical aptitude are: intellectual, spatial (spatial relations and visualization), perceptual (ability to perceive small and insignificant differences between two similar objects), mechanical comprehension (ability to understand and solve mechanical problems), and mechanical knowledge.

According to Tyler (1965) there are two classes of ability which together constitute mechanical aptitude. The first involves the understanding of mechanical relations, the recognition of tools and related intellectual skills, and the second involves the ability to visualize how parts or components fit together as a whole. The mechanical experience factor has been identified by other writers (Dudek, 1948; Ekvall, 1969; French, 1951; Guilford, 1948; Guilford & Lacy, 1947; Guilford & Zimmerman, 1947), as has the visualization factor (Theologus, Romashko, & Fleishman, 1970; Thurstone, 1949, 1950, 1951).

McCormick and Tiffin (1975) identified two activities present in mechanised jobs; that is, cognitive and motor activities. While accepting that physical aspects are present, they emphasized the essential nature of the cognitive aspects. They believed that knowledge gained from mechanical experience is the most important aspect of mechanical aptitude.

Skawran, Van der Reis, and Moore (1967) believed that two essential aspects of mechanical aptitude are the "need for three-dimensional comprehension" and the "ability to trace faults" (p. 160). They asserted that

> If one considers the activities of a mechanic, ... one finds that the ability to trace faults is not only one of the most important abilities expected of a good mechanic, but it is also that ability in which mechanical thinking comes most into play. (p. 165)

3.2 Factor studies of mechanical aptitude

3.2.1 Cognitive studies

3.2.1.1 Early research

Two of the earliest significant attempts to study mechanical aptitude were conducted by Cox (1928) in England, and by Paterson and his associates at the University of Minnesota (Paterson et al., 1930).

Cox (1928), basing his theory on Spearman's (1904, 1914, 1927) two-factor theory hypothesized that mechanical aptitude would consist of 'g' and a specific mechanical ability factor. Using a specially constructed mechanical apparatus, which did not, however, lend itself to scoring, he isolated a factor 'm' in addition to 'g', which appeared to be of importance in mechanical tasks and which he defined as 'mechanical aptitude', but which Super (1949) asserted was more spatial than mechanical in character.

At about the same time Paterson et al. (1930) conducted the extensive Minnesota study aimed at discovering and measuring mechanical aptitude in junior high schoolboys.

Psychometric research at that time was influenced by Spearman's (1927) two-factor theory on the one hand, and the theory of unique traits on the other (Hull, 1928). Paterson and his colleagues (1930) were interested in the organization of mechanical aptitude because of its implications for the important question of whether it is possible "for an individual to be distinctly gifted in one line of mechanical work and to possess poor or mediocre capacity in others, i.e. is there <u>a</u> mechanical ability which is distinct from all others or a <u>group</u> of abilities" (Wittenborn, 1945a, p. 241). However, unlike Cox (1928) in England, the American researchers did not have available to them at that time the more advanced factor analytic theories and procedures which would have facilitated this research, and thus much of the factor analytic information on the Minnesota study comes from Harrel (1940) and Wittenborn (1945a, 1945b).

In the Minnesota project, the Minnesota Mechanical Assembly (Paterson et al., 1930), Link Spatial Relations and Paper Formboards tests were administered to junior high schoolboys, together with the Otis Self-Administering Test (Otis, 1922), the Stenguist Mechanical Aptitudes and Picture Tests (Stenguist, 1923), and an interest inventory. Many of the tests were modified during the programme to improve their reliability; the Link Spatial Relations and Paper Formboards becoming the Minnesota Spatial Relations Test and Minnesota Formboards, and the revised Stenguist becoming the Minnesota Assembly Test.

Paterson et al. (1930) adopted a 'theory of unique traits' and thus tried to eliminate the intellectual factor whilst placing emphasis on obtaining measures of mechanical skill rather than knowledge or theory. Results from the study, however, are an indication that it is not possible to eliminate general intelligence from mechanical ability, which led Bingham (1937, p. 176) to point out succinctly that "a person's competence in a trade resides more in his head than in his hands. Manual dexterity is not the primary requisite".

The design and analysis of the Minnesota Project was criticized by other researchers (Harvey, 1931; Wittenborn, 1945a, 1945b). In accordance with Spearman's (1904, 1927) theory, Paterson et al. (1930) selected dissimilar tests for their battery. Wittenborn (1945a) believed, however, that it was this which was responsible for their obtaining a general factor. Had more similar tests been selected, a group factor would probably have been obtained.

Harrel (1940) applied Thurstone's (1931) centroid method of factor analysis to the Minnesota Battery which he administered to 91 cotton-mill machine fixers, together with more than 30 other tests and measures of biographical variables of age, education, and mechanical experience. Both orthogonal and oblique solutions were obtained with the oblique appearing to yield the most satisfactory solution. Five factors were isolated: perceptual, verbal, youth, manual agility, and spatial. The prominent factors, on which the mechanical ability tests loaded, were the perceptual, which was equivalent to Thurstone's (1938) P; and spatial, similar to Thurstone's (1938) S. The S factor was defined at that time as a facility in spatial and visual images. None of the Minnesota tests loaded on the manual agility factor. A point made by Harrel (1940) and Vernon (1950) was that there is evidence to indicate that pencil-and-paper tests cover the same ground as practical, mechanical, or performance tests, apart from a small dexterity component.

Harrel (1940) concluded from his analysis that the main factors constituting mechanical aptitude are spatial and perceptual. He interpreted the latter as the ability to scan quickly a visual configuration and pick out significant details and classify them, and regarded the spatial factor as the equivalent of mechanical ingenuity. Vernon (1961), however, believed Harrell's (1940) perceptual factor to be more mechanical in character than perceptual.

Wittenborn (1945a) applied the same factorial method to the data of the Minnesota study but used an orthogonal solution. Six orthogonal factors were extracted, of which the first four were clearly defined: spatial, visualization, stereotyped movement, manual dexterity, perceptual, and steadiness. The Minnesota Spatial Relations Test, the Minnesota Mechanical Assembly, the Minnesota Paper Formboard Test, and the Stenguist Picture Test, all loaded on the visualization factor, although the Spatial Relations Test loaded on the manual dexterity factor as well (0,4). As the Mechanical Assembly Test was taken to be the "prototype of Mechanical Aptitude" (Super, 1949, p. 222) these loadings may be taken to suggest that spatial visualization is an important component of mechanical aptitude.

In another study, Wittenborn (1945b) used the results of the Minnesota experiment proper (Paterson et al., 1930) as a means of further investigating the manual dexterity factor. Wittenborn (1945b) isolated four factors, the first two being correlated; size, strength, spatial visualization, and manual dexterity. The Spatial Relations Test, the Paper Formboard Test, and Minnesota Assembly Test, an interest analysis blank, and a quality criterion loaded on the spatial visualization factor. Here again performance tests of spatial relations and mechanical assembly failed to load on the manual dexterity factor.

Slater (1940) in another analysis of Cox's (1928) mechanical assembly test also reported no special mechanical ability factor over and above general intelligence and spatial visualization. However, this inability to isolate a 'mechanical' factor is in part a function of the type and the number of tests used, as in order to overdetermine a factor, one requires more than one test to define the factor clearly (Ballentine, 1982; Grant, 1969; Super, 1949; M.A. Verster, 1976).

3.2.1.2 Military research

The Classification and Replacement Branch (Staff, Personnel Research Section, 1945) of the army factored the results of 48 paper-and-pencil mechanical aptitude tests and six apparatus tests, including the Minnesota Paper Formboard, Spatial Relations, and manual dexterity tests, which had been administered to a large number of army personnel. Eleven orthogonal factors, of which the last three were psychomotor, were extracted, namely: verbal, number, spatial, intelligence, two perceptual factors, speed, logic, aiming, finger dexterity, and manual dexterity.

The extensive work undertaken by the Army Air Force (AAF) Aviation Psychology Program (Fruchter, 1952a, 1952b, 1954; Guilford et al., 1952; Guilford & Lacy, 1947; Guilford & Zimmerman, 1947) in which tests were administered to thousands of military personnel, is helpful in shedding some further light on the question of what other factors play a part in mechanical aptitude.

Guilford and Zimmerman (1947) were two of the earliest researchers providing clear evidence of the existence of separate spatial abilities. They summarized the extensive AAF study (Guilford & Lacy, 1947) and listed 27 factors, of which 10 were named with relative certainty, namely: verbal, numerical, perceptual speed, associate and visual memory factors, length estimation, space (ability to perceive spatial order or relationships); visualization (on which the mechanical comprehension tests loaded), psychomotor co-ordination, and mechanical experience.

A test of mechanical information and achievement patterned on the Bennett Mechanical Comprehensive Test (Bennett, 1940) was found by Guilford and Zimmerman (1947) to be saturated with two factors: spatial visualization and mechanical information. In general, the important elements in the mechanical apparatus tests were the spatial visualization, perceptual, and mechanical information factors which they measured (Super, 1949; Super & Crites, 1962). The major contributions of the AAF programme, however, lie in Guilford and Zimmerman's (1947) demonstration of the distinction between the spatial factors.

Guilford et al. (1952) in a further investigation for the AAF analysed a battery of 37 experimental and seven reference tests. Twelve orthogonal factors which could be interpreted were extracted, including spatial relations and visualization factors, thus offering confirmation of Guilford and Zimmerman's (1947) findings with respect to these factors. The spatial factor is similar to Thurstone's (1949) S_3 whereas visualization is similar to S_2 (see section 3.2.1.3). A Mechanical Principles Test of the Bennett-Fry format (Bennett, 1940) had one of the highest loadings (0,60) on visualization, whereas a Paper Formboard Test loaded surprisingly on perceptual speed instead of visualization. Zimmerman (1953) however, refactored Thurstone's (1938) PMA and extracted both spatial and visualization factors, with a formboard test having the higher loading on visualization (0,62) and the Mechanical Movement having a lower loading (0,40).

Fruchter (1952a) in a study to investigate ability patterns in technical training criteria found that the highest criteria loadings for airplane and engine mechanics, for aircraft sheetmetal workers and for craftsmen were on mechanical and visualization factors, whereas for electricians, the highest loadings were on numerical, verbal, and mechanical experience. This seems to imply that electricians do not require the same spatial abilities as mechanics, which confirms the view (Skawran et al., 1967) that the essential difference distinguishing an electrician and a mechanic is to be found in the latter's ability to handle the three-dimensional nature of a mechanical task.

3.2.1.3 Thurstone's research

Thurstone (1949, 1950, 1951) together with his wife (Thurstone & Thurstone, 1949) conducted intensive investigations in order to identify the primary mental abilities that characterize mechanical aptitude. The investigation was based on the assumption that mechanical aptitude is mostly "in the head" (Thurstone, 1951, p. 1) and is a complex of intellectual abilities.

Thurstone (1949) accordingly administered 32 group tests to a sample of 350 boys at a technical high school in Chicago. Most of the tests were non-verbal, but measures of mechanical skill, experience, and training were included to facilitate interpretation of the factors. In addition two interest schedules, the Thurstone Inventory and the Kuder Preference Record (Kuder, 1939) were included to permit the differentiation of subjects who had a dominant interest in mechanical things from those who were indifferent to, or even disliked, mechanical things. (A detailed description of the tests may be found in Thurstone and Thurstone, 1949.)

The correlation matrix was factored using Thurstone's (1947) complete centroid method and subjected to an oblique solution. Ten factors were extracted of which nine could be interpreted: Induction (I), three space factors (S_1; S_2; S_3), two memory factors (M_2; M_3), a kinaesthetic factor (K), and two closure factors (C_1; C_2).

Because these factors have formed the basis of many studies in the years after Thurstone's (1949) initial study, and because these factors have regularly been extracted by other researchers, they will now be discussed in more detail.

(a) Induction (I): The ability to derive a principle from a number of particular instances. Tests with high loadings were Letter Series, Letter Grouping, and Figure Analogies. Mechanical Movements had a low (0,21) loading and the criterion measure of Mechanical Comprehension correlated significantly ($\underline{r}$ = 0,48; $\underline{p}$ < 0,001) with Induction. Thurstone (1949) believed that the postulation of the concept of inductive reasoning in mechanical aptitude is a plausible one, particularly with regard to 'trouble-shooting' or 'fault-finding' tasks, as the individual is required to trace successive displacements of the component parts through a series of logical steps in order to solve the problem (Skawran et al., 1967).

In another study (Thurstone & Thurstone, 1941) on Primary Mental Abilities, it was noted that the inductive or reasoning factor R had the highest correlation with the second-order general factor ($\underline{r}$ = 0,84). Pemberton (1952) hypothesized that a second-order factor analysis of Thurstone's (1949, 1950) mechanical aptitude data would have inductive reasoning, space, and speed of closure on one factor, thus tending to confirm Thurstone's (1949, 1950) belief in the importance for mechanical aptitude of reasoning.

(b) First Space Factor (S_1): Defined by Thurstone (1949, p. 13) as "the ability to visualize a rigid configuration when it is moved into different positions". S_1 is thought to be a combination of Guilford and Zimmerman's (1947) S_1 (SR) and visualization factors. Tests loading on S_1 were Cards, Figures, Reversals and Rotations, and Rotation of Solid Figures.

(c) Second Space Factor (S_2): "the ability to visualize a configuration in which there is movement or displacement among the parts of the configuration" (Thurstone, 1949, p.13). This factor had the highest saturation in the three criterion measures of Mechanical and Electrical Experience (0,66 and 0,50) and Mechanical Comprehension (0,60), and its interpretation is thus of central importance. Tests which loaded on this factor all involve configurations in which there is some internal movement and displacement or even deformation among the parts, and this characteristic is also an essential element of the three criterion measures. In the light of these findings, Thurstone (1949) hypothesized that the ability to visualize a flexible configuration is essential for the development of mechanical skills. Interestingly enough, this had not been one of Thurstone's (1949) original hypotheses on which the investigation was based. The second space factor is the same as Guilford and Zimmerman's (1947) visualization factor (Thurstone, 1950). Whereas both S_1 and S_2 involve visualization in Guilford and Zimmerman's (1947) terms, a rigidity versus internal displacement dichotomy separates the two. The essential difference between S_1 and S_2 is not movement or rotation; if the configuration is rigid, it seems to involve S_1, but if there is internal displacement among the parts, it seems to involve S_2.

(d) Third Space Factor (S_3): "the ability to think about those spatial relations in which the body of the observer is an essential part of the problem" (Michael, Guilford, Fruchter, & Zimmerman, 1957,

p. 188). The third space factor is thus characterized by the participation of bodily orientation on the part of the subject, although it appears to be distinct from the factor of kinaesthetic imagery, and is similar to Guilford and Zimmerman's (1947) 'spatial relations' factor.

(e) Second Memory Factor (M_2): "the ability to recall past experience which one did not intend to be memorized" (Thurstone, 1949, p. 15). The second memory factor is distinct from the first memory factor (M_1), which was identified in a previous study (Thurstone, 1938) and which he defined as the ability to memorize intentionally, whereas M_2 is related to incidental memory.

(f) Third Memory Factor (M_3): "the ability to keep in mind some perceptual detail" (Thurstone, 1949, p. 16). Thurstone (1951), however, suggested that M_3 might have been misclassified and that it should be identified as a perceptual rather than a memory factor.

(g) Kinaesthetic Factor (K): tentatively described as a factor representing kinaesthetic imagery. Michael et al. (1957) interpreted K as representing a left-right discrimination.

(h) Speed of Closure (C_1): "ability to fuse a perceptual field into a single percept" (Thurstone, 1949, p. 16) when the presented field is entirely unstructured. This is the same factor identified previously (Thurstone, 1944, p.16) and is similar to Harrel's (1940) P factor. C_1 had an unexpectedly low saturation (0,22) in Mechanical Experience.

(i) Flexibility of Closure (C_2): "ability to keep in mind a configuration against distraction" (Thurstone, 1951, p. 20). This factor had been obtained in previous studies (Bechtoldt, 1947; Thurstone, 1944). Flexibility of closure was represented in the criterion measurement of Mechanical Comprehension (0,21, $p < 0{,}001$) and correlated significantly with both Mechanical Comprehension ($r = 0{,}50$, $p < 0{,}001$) and Mechanical Movements ($r = 0{,}37$, $p < 0{,}001$). The Gottschaldt Figures Test (Thurstone, 1951), a test of field independence, loaded on C_2 (0,30).

The difference between C_1 and C_2, which were correlated, is primarily that C_1 facilitates closure in an unstructured field, whereas C_2 facilitates retention of a figure in a distracting field. Thurstone (1949) hypothesized that if the interpretation of the factors were generalized beyond the perceptual domain, C_1 might determine the ease with which a person can unify a complex situation, and thus be associated with inductive thinking. Flexibility of closure (C_2) might then determine the ease with which a person keeps in mind against distraction the essential features of a given field, and thus it might be more associated with deductive thinking. This hypothesis has been borne out to an extent by Pemberton (1952) who found evidence that flexibility of closure generalizes to the cognitive domain and is associated with analytical problem solving ability.

Although S_1 and S_2 were correlated ($\underline{r}$ = 0,31, $\underline{p}$ < 0,001), Thurstone (1951, p. 18) asserted that "the clear separation of the second space factor from the previously identified space factor S_1 can be regarded as the major finding of this analysis in relation to our major objective". The high loadings of S_2 (0,66 and 0,59) on the criterion measures of Mechanical Experience and Electrical Experience respectively are also of paramount importance.

On the basis of the results of the criterion tests and the Kuder Preference Record (Kuder, 1939) score, Thurstone (1950, 1951) selected two criterion groups of boys to whom he administered 25 individual tests. One group of 65 boys was high in both mechanical experience and knowledge scores and in mechanical interest, whereas the second group of 45 boys was selected on the basis of low mechanical experience scores and low mechanical interest ratings. A comparison between the two groups yielded the following results:

Most of the tests differentiated. Thurstone (1950, 1951) found that the group tests differentiated between the groups as well as, if not better than, the individual tests. The individual tests which differentiated best were those involving the ability to see relationships between several mechanisms, namely the Crissey, Purdue

Assembly, Minnesota Assembly, Stencil Designs, Kent-Shakow Formboard, and the Wiggly Blocks, with *t*-values between 0,60 and over 0,80. (For more information regarding the tests see Thurstone, 1951, p. 10.)

The tests differentiating least required relatively little mental effort or mechanical insight. Almost all the group tests differentiated between the two groups, but those high on the second space factor seemed to differentiate best, namely: Mechanical Movements ($t = 8,2$, $p < 0,005$), Surface Development ($t = 7,8$, $p < 0,005$), Block Assembly ($t = 6,1$, $p < 0,005$), Gottschaldt Figures ($t = 5,8$, $p < 0,005$), Block Counting ($t = 5,7$, $p < 0,005$), Paper Puzzle ($t = 5,7$, $p < 0,005$) and Lozenges ($t = 5,0$, $p < 0,005$). These tests also had loadings on C_2 and S_1, but not to the same extent.

An interesting point is that one of the group tests which did not differentiate was the Hands Test, whereas the Bolts Test did. Both tests define and have high saturations in K (0,52). Thurstone (1950, 1951) hypothesized that it might be an experience factor tapped in the Bolts Test and that this might be the important distinguishing element. The low differentiation of the Jig Saw Test ($t = 0,7$) might be an indication that mechanical aptitude is not characterized in any essential way by the ability to make fine discriminations.

Thurstone (1951, p. 25) asserted that "the second space factor is heavily represented in mechanical aptitude" and that the S_1 and C_2 factors contribute to a lesser extent, as does I and he concluded that "it looks as if an essential characteristic of mechanical aptitude is the ability to visualize a flexible configuration" (1951, p. 19).

Patterson (1956), in a review of research into mechanical aptitude, commented that while a number of apparently independent factors have been isolated, the imposition of an orthogonal solution does not reflect the facts accurately, as many of the abilities are correlated. An oblique solution is often better in terms of simple structure. In addition, many of the tests are not pure; the Bennett test (1940) includes both mechanical experience and visualization components, and paper formboard tests include visualization, perceptual, and inductive reasoning factors. In fact, Guilford and Lacy (1947) made the point that none of the visualization tests are pure, and most contain, in addition, spatial and/or mechanical experience factors.

Indeed, the controversy over the nature of the spatial factors rages on, and factor analysts continue to have difficulty in differentiating the two factors of spatial relations and visualization (Carroll & Maxwell, 1979; Harris, 1981; MacFarlane-Smith, 1964; Mandler & Stein, 1977; McGee, 1979; Michael et al., 1957; Myers, 1958; Patterson, 1956; Vandenberg, 1975; Zimmerman, 1954a, 1954b). This topic will be elaborated upon, in a later section (see section 3.3.1).

Patterson (1956) concluded that mechanical aptitude consists of at least two factors in addition to general intelligence, namely, visualization and mechanical knowledge or experience, with a spatial factor probably also present. Vernon (1961) and Ross (1962) working within the British model commented that although researchers involved in studies of mechanical aptitude have shown the existence of spatial and mechanical information factors (French, 1951; Fruchter, 1952a, 1952b; Guilford & Zimmerman, 1947; Zimmerman, 1953), tests of these factors have never achieved the high reliability and validity of those associated with the v:ed field as so much depends on experience, training and background. In fact, Vernon and Parry (1949) pointed out that k:m tests are more useful for predicting trainability for mechanical jobs for adolescent males and among women than for male adults, and they ascribed this to differentiation of k:m into more complex structures when specialized functions are practised, thus resulting in alterations to the structure of mechanical aptitudes.

3.2.2 Psychomotor studies

The research on the structure of intellect has provided substantial evidence to support the notion of a broad general factor of intelligence (Burt, 1940; Vernon, 1950). De Wet (1967) pointed out that on mainly the strength of this, the assumption was made by early investigators that a general factor of motor ability or 'handiness' also exists.

Whereas, however, there is considerable experimental evidence to indicate that tests of intellectual ability tend to intercorrelate quite substantially, factor analyses of psychomotor tests have shown a comparatively high degree of specificity (Biesheuvel, 1979; De Wet, 1967; Fleishman & Hempel, 1954a; Melton, 1947; Muscio, 1922; Perrin, 1921; Seashore, 1940; Vernon, 1961; Vernon & Parry, 1949; Wolfle, 1940), which is an indication that there is thus no general factor of psychomotor ability. Fleishman and Hempel (1954a) have found that while measures of gross physical abilities involving bodily movement, strength, and the mobilization of energy, tend to intercorrelate quite highly, hardly any relationships exist between these activities and the fine motor skills involving precise motor co-ordination. Furthermore, different measures of the latter tend to show very small intercorrelations.

Thus Vernon (1950) and Burt (1940) do not, in fact, define a psychomotor group factor as such. According to Biesheuvel (1979) the psychomotor abilities, at best, are defined by minor group factors, particularly specific, task-oriented ones.

Vernon and Parry (1949) in a large-scale study for the British Services found that pencil-and-paper tests involving the k:m factor were better predictors of training success than manipulative tests, thus indicating the involvement of non-motoric factors. Other researchers have confirmed this (Biesheuvel 1979; De Wet, 1967; Fleishman, 1953; Fleishman & Hempel, 1954b). In factor analytic studies, performance tests have failed to show significant loadings on manual dexterity but have incorporated spatial, visualization, and perceptual factors (French, 1951; Grant, 1970a; Guilford & Zimmerman, 1947; Paterson et al., 1930).

Wittenborn (1945b) factor analyzed the Minnesota experiment results to investigate the manual dexterity factor and obtained four factors, the first two intercorrelated: size, strength, spatial visualization, and manual dexterity. The performance tests of spatial relations and assembly did not load on manual dexterity. Wittenborn (1945b) commented that unlike tests of mental abilities where variables are independent of exact mode of expression, tests contributing to motor abilities appear to be dependent on quality of muscular performance.

Large-scale investigations carried out for the United States Army Air Force research programme on motor and dexterity tests led to the identification of a large number of psychomotor factors (Fleishman, 1953; Fleishman & Hempel, 1954a, 1954c, 1956). That the concept of manual dexterity as a unitary variable is untenable has also been clearly demonstrated.

Fleishman (1954) administered a battery of 28 performance and 11 pencil-and-paper tests to 400 airmen undergoing basic training. Twelve factors were extracted using Thurstone's (1931) centroid method, and 'blind' orthogonal rotations were carried out. Twelve factors were obtained, 11 of which could be interpreted:

- wrist-finger speed
- finger dexterity
- rate of arm movement
- arm-hand steadiness
- reaction time
- manual dexterity
- psychomotor co-ordination
- spatial relations
- postural discrimination
- aiming
- psychomotor speed

The last two factors loaded only on the pencil-and-paper tests.

From a study conducted by Fleishman and Hempel (1954b) it is apparent that different factors are involved at different stages in the learning of a psychomotor task. The researchers administered a complex co-ordination test, together with 18 reference tests (12 paper-and-pencil and six apparatus tests) to 197 airmen in basic training. The matrix of intercorrelations was subjected to Thurstone's (1931) centroid method of factor analysis. The results obtained are indicative of considerable, but systematic changes, in the factor structure of the task as practice continued. The co-ordination test became factorially less complex and the factors contributing to the variance at the early stages were different from those contributing at later stages of practice. In the early learning trials, 'non-motor' factors, which were probably spatial and verbal (Biesheuvel, 1979; De Wet, 1967) played a major role, whereas in later trials they correlated far less with performance. During the early trials test specific factors initially had rather small correlations with performance but as practice continued, variance in performance specific to the task increased. This observed transition in factor structure to a less factorially complex task with practice has been confirmed by Schepers (1962) with an elementary and principal components analysis of a hand and foot reaction time test. He found that test performance became less complex factorially as practice continued and the subject became more familiar with the task. A single 'order of complexity' factor appeared to account for the hierarchical gradient observed in the inter-trial correlation matrix. These findings are, perhaps, in line with the idea that cognitive abilities play a more important role in earlier stages of a learning task than in the later stages when performance becomes organized into a habituated psychomotor pattern. The role of non-motor factors in psychomotor tasks has been extensively reported in the literature (Biesheuvel, 1979; De Wet, 1967; Fleishman, 1953; Fleishman & Hempel, 1954b; Vernon & Parry, 1949).

De Wet (1967) asserted that "the degree of relationship among sensory-motor tests and between these and intellectual tests can be markedly influenced by the composition of the sample" (p. 25). Thus, in selected 'high-grade' and homogeneous samples, the intercorrelations will be smaller than in heterogeneous 'low-grade' groups where cultural differences account for much of the variance observed (Ferguson, 1954, 1956). A study by Vernon (1949) illustrates this point for correlations among sensory-motor tests were considerably lower for a sample of pilot trainees than for a sample of African mineworkers. De Wet (1967) speculated that sensory-motor abilities are linked with 'g' via the spatial mechanical group factor (k:m)

(Vernon, 1949, 1950). Other studies appear to have confirmed this (Attenborough & Pitt, 1934; Malpass, 1960).

3.2.3 Psychomotor skills with regard to Blacks

Biesheuvel's (1979) comment that

> ... the view has frequently been expressed ... probably not without some bias, that Blacks in Africa are slow in acquiring industrial skills, and that many, despite training and much practice, do not reach the standard of proficiency expected of Whites. (p. 272)

perhaps sums up some of the attitudes prevalent in industry in recent years with regard to the 'clumsiness' of Black workers. Indeed, Biesheuvel (1961a) reported that the average performance of African workers in several tests of manual skill fell below that of White workers. Black operators, however, have been shown to be as competent as Whites on machine tasks involving manual dexterity (Hudson, 1955; Kilby, 1961), although when the tasks become more complicated, difficulties arise relating to the transfer, co-ordination, and integration of several tasks, which points to the complex nature of psychomotor tasks.

As has been discussed previously (see section 3.2.2) no general psychomotor factor has been reported for Whites. Similarly, De Wet (1967) found no "indication of a general factor of dexterity or handiness" (p. 30) when he administered six simple sensory-motor tests to 125 African adults. This was true even of the less educated sample, where intercorrelations might have been expected (Attenborough & Pitt, 1934; Malpass, 1960). Interestingly enough, educational level appeared to be unrelated to performance on the sensory-motor tasks in De Wet's (1967) study.

A study which has implications for the training of Blacks for skilled industrial work was conducted by Biesheuvel (1963). On a simple manual dexterity task on which White graduates, Black graduates, and illiterate mineworkers were tested, their performance ranged in that order, the White graduates being superior to both of the other groups. Whereas the relatively narrow gap between the White and Black graduates closed after about 40 trials, the performance curve of the Black mineworkers appeared to reach an asymptote after about 40 trials indicating that no further improvement was likely. The mean score in seconds of the mineworkers was about twice that of the graduates. The conclusion drawn by Biesheuvel (1963) was that the acquisition of skill is a function of intensity, length, and early exposure to Western culture. This accounted for the superior performance of the White and Black graduates, whereas the Black mineworkers, reared in traditional tribal environments, having had little opportunity for manipulating and using mechanical devices and implements, had reflected their relatively disadvantaged background.

Vernon (1969) came to a similar conclusion, when he attributed the so-called retarded development of 'practical' intelligence in African subjects to "inadequacies of psychomotor experience throughout childhood ... and the absence of interest in constructive play or cultural pressures to practical achievements" (1969, p. 342).

In the light of the aforegoing comments a warning by Biesheuvel (1979) is apposite:

> The assumption that in traditional environments opportunities for structuring of the basic abilities entering into the manipulative skills involved in industrial and technological tasks are lacking has not been tested. It is probable that the skills of the potter, basket weaver, hut builder, spear thrower, makers and players of musical instruments, mowers and decorators are highly specific and that the schemata involved in the development of these abilities do not enter into the psychomotor skills with which we are concerned. But this may not be so, as the remarkable achievement of rural Black youngsters in putting together quite complicated models of motor vehicles and other mechanical devices points to some transferability. (pp. 288-289)

Thus Biesheuvel (1979) amended his earlier rather deterministic interpretation (Biesheuvel, 1963) to account for certain factors which possibly affected the results in an adverse manner. The first factor pertained to the unfamiliar experimental conditions of the test situation with which the illiterates were faced, and to the low need for achievement frequently found in members of traditional societies (Baran, 1970; Biesheuvel, 1979), particularly on tasks which have no intrinsic meaning. The second factor pertained to the different abilities which might operate at various stages of the learning task (Fleishman & Hempel, 1954b; Heinonen, 1962; Schepers, 1962). The non-motor factors which predominated at the beginning were most likely in this case to have been space and orientation factors together with insight into the nature of the task. The better educated and more intelligent subjects should have been able to deal more effectively with these aspects than illiterate or barely literate mineworkers. Thus Biesheuvel (1979) concluded that:

> As psychomotor skills differ considerably in factor patterns and degree of specificity, it would be wrong to conclude that because co-ordination tasks are affected by failure to establish certain schemata in early childhood this would apply generally, for instance, to dexterity tasks. That there is no general psychomotor factor has been convincingly demonstrated and what applies to one basic motor factor may not apply to another. (p. 288)

3.3 Spatial factors

3.3.1 Studies of spatial factors

Unlike the relatively simple spatial factor reported by British researchers (Burt, 1940; El Koussy, 1935; Vernon, 1950), a number of spatial factors were identified in the extensive American investigations initiated during the early fifties (Ekstrom, French, & Harman, 1976; French, 1951; Fruchter, 1952a; Guilford & Zimmerman, 1947; Roff, 1952; Thurstone, 1938, 1949, 1950, 1951). It is apparent that a great deal of confusion over the spatial factors existed, and a 'Space and Visualization Committee' was set up in 1955 to classify and integrate the factors identified by Thurstone (1938, 1949, 1950), by the Army Air Force (Guilford & Zimmerman, 1947) and by French (1951).

According to the report of the committee (Michael et al., 1957) there are at least two types of spatial factors:

- spatial relations and orientation (SR-O)
- visualization (Vz)

while a third factor, kinaesthetic imagery (K) has not yet been clearly defined. Because these factors have formed the basis for many studies, and because there is little agreement as to the interrelationships among the various components of spatial ability, they will be described in some detail.

3.3.1.1 Spatial relations and orientation (SR-O)

SR-O is described by Michael et al. (1957) as the ability to "comprehend the nature of the arrangements of elements within a visual stimulus pattern primarily with respect to the examiner's body or frame of reference" (p. 189). The essential feature of SR-O appears to be that mental rotation of the whole figure is required (Ekstrom et al., 1976; McGee, 1979).

According to Michael et al. (1957) and McGee (1979) the factors which constitute SR-O are the following (where these have been identified or endorsed by other theorists, the references have been included in parentheses):

- SR:	(Guilford & Zimmerman, 1947)
- S : Space	(French, 1951)
- SO: Spatial orientation	(French, 1951)
- S_1: First space	(Thurstone, 1950)
- S_3: Third space	(Thurstone, 1950)
- S :	(Ekstrom et al., 1976)

Ballentine (1982) commented on the anomaly of Michael et al.'s (1957) classification of SR-O together with Thurstone's (1949, 1950, 1951) S_1 and S_3 factors. He speculated that the most important distinction between the two factors is that S_1 tests require essentially two-dimensional rotation, whereas S_3 tests require essentially three-dimensional rotation. Two of the factors which Ballentine (1982) extracted (Factor 1 and Factor 8) seem to confirm that this distinction may have a meaningful basis. French's (1951) SO factor may be similar, as French (1951) indicated that dimensionality is not an essential characteristic of the factor. By 1963, however, French, Ekstrom, and Price no longer regarded the two factors as being distinct entities.

3.3.1.2 Visualization (Vz)

This factor is defined by Michael et al. (1957) as requiring mental manipulation of visual objects involving a specific sequence of movements. The individual has to "mentally rotate, turn, twist or invert one or more objects or parts of objects of a configuration" (p. 191).

The factors constituting Vz are thought to be:

-	Vz: Visualization	(Guilford & Zimmerman, 1947)
-	S_2: Second space	(Thurstone, 1950)
-	Vi: Visualization	(French, 1951)

According to McGee (1979), the underlying ability seems to

> involve a process of recognition, retention and recall of a configuration in which there is movement among the internal parts (S_2); manipulation of an object in three-dimensional space (Vi); or the folding and unfolding of flat patterns (Vz). (p. 19)

3.3.1.3 Kinaesthetic imagery (K)

This is a factor, only tentatively postulated, which "represents merely a left-right discrimination with respect to the location of the human body" (Michael et al., 1957, p. 191).

The factors constituting K are thought to be:

- S(?):	(Guilford & Zimmerman, 1947)
- K : Kinaesthetic factor	(Thurstone, 1950)

French et al. (1963) omitted K from their test batteries and did not attempt to classify it -- most likely because of its tentative nature. Ballentine (1982) argued that although a knowledge of left and right assists one in doing the tests which load on this factor, it is more likely to be spatial in character than kinaesthetic. He pointed out that the Army Air Force psychologists (Guilford & Lacy, 1947) classified it accordingly as a spatial factor.

3.3.1.4 Difficulties in defining spatial factors

A statement made by Vandenberg (1975) that there is no agreed upon conceptual or operational definition of spatial ability highlights the confusion surrounding the usage of these spatial terms in the literature, and the difficulties which factor analysts continue to have in differentiating and interpreting these two spatial factors, SR-O and Vz, and the nature of their underlying processes (Carroll & Maxwell, 1979; Harris, 1981; Horn, 1972; Mandler & Stein, 1977; McGee, 1979, 1982; Myers, 1958; Newcombe, 1982; Patterson, 1956; Zimmerman, 1954a). Harris (1981) asserted that attempts to identify various components of spatial tests are mainly guesswork and he attributed much of this to not only a lack of standardization of the factor analyses, but also to possible differences pertaining to the factor structure of skilled and unskilled individuals as has been demonstrated by Grant (1969) and Irvine (1969a).

Both SR-O and Vz, as well as other factors in the perceptual domain, such as perceptual speed, could be said to involve some kind of mental encoding and representation of spatial configurations along with other 'mental rotation' operations (Shepard & Feng, 1972; Shepard & Metzler, 1971).

The essential distinction between SR-O and Vz appears to be that the former involves mental rotation of a rigid configuration, whereas Vz involves mental manipulation where there is internal displacement among the parts. Both SR-O and Vz require short-term memory, but Vz requires mental rotation and serial operations (Ekstrom et al., 1976; MacFarlane Smith, 1964).

Egan (1976) however, differentiated between accuracy and speed scores in spatial tasks. He suggested that accuracy scores on SR-O tests represent "a form of concept verification in which the examinee serially checks the three spatial dimensions of a figure against the concept of what the figure should be" (p. 24), whereas Vz tests "have properties analogous to physically turning an object in space, so that problems requiring a greater number of turns or turns of greater length required more time to solve" (p. 24).

Hence Carrol & Maxwell (1979) suggested that the essential element in Vz is the speed of mental rotation, while SR-O taps the ability of the subject to encode a visual form in order to compare it with another. The observed differences between speed and accuracy scores have been confirmed in later studies (Ballentine, 1982; J.M. Verster, 1982).

Carroll and Maxwell (1979) also suggested that individuals change their information processing strategies depending on the nature of the case. Indeed, visualization has been shown to contribute to the solution of mathematics problems (French, 1965; Guilford, Green & Christensen, 1951; McGee, 1982).

Horn and Cattell (1966) conceived of visualization as being a factor distinct from the spatial-perceptual-mechanical spectrum of Vernon (1950) and Burt (1940, 1949).

It has been observed, however, in a number of studies (Borich & Bauman, 1972; Goldberg & Meredith, 1975; Horn, 1972; Karlins, Scheurkoff, & Kaplan, 1969; Michael et al., 1957; Roff, 1952; Thurstone, 1949, 1950, 1951) that spatial orientation and visualization factors are correlated, the degree of correlation depending on the population being tested and the tests used (Michael et al., 1957). Roff (1952), for example, reported a correlation as high as 0,75 ($p < 0,001$) between SR-O and Vz.

Zimmerman (1953) refactored Thurstone's (1938) PMA tests and extracted both spatial and visualization factors, and suggested that the two factors represent levels of complexity of essentially the same dimension, and as the level of difficulty of the items increases, so the emphasis on perceptual speed, spatial relations, and visualization increases in that order.

Zimmerman (1954a), in a study designed to test this hypothesis, was able to confirm it, although Pawlik (1966) and Royce (1973) discounted this explanation. Zimmerman (1954b) stressed that individual test items differ in level of difficulty for subjects, thereby causing the subjects to use different problem-solving strategies. This would tend to confound the factorial research, in which attempts have been made to subdivide the space factor. The effects of different problem-solving strategies on factor loadings have also been pointed out by French (1965).

Indeed, Guilford and Lacy (1947) asserted that "no visualization test is pure for the factor" (p. 857). Most contain, in addition to visualization, spatial relation and orientation, and mechanical experience factors (French, 1951; Guilford & Lacy, 1947; McGee, 1979; Michael et al., 1957; Wittenborn, 1945b)

3.3.2 Studies of spatial factors with regard to Blacks

Grant (1969, 1970a) attempted to overdetermine the dimension represented by the Form Perception Test (Grant & Schepers, 1969) in his preliminary study on the structure of intellect in Africans. Paper-and-pencil tests, with two-dimensional representation of three-dimensional objects have been used in most studies in America and Britain. Recognising Hudson's (1960) findings with regard to the difficulties experienced by Blacks in perceiving depth in pictures, and the difficulty of working with pencil-and-paper tests with illiterate samples, Grant (1970a) decided to use performance tests, although acknowledging that this in itself could alter what he was attempting to measure.

Grant (1970a) administered to 100 African mine recruits his 'spatial battery' of tests, which included the General Adaptability Battery (Biesheuvel, 1952a) four Formboards, a Fill-the-Squares Test, and a test of Abstract Spatial Relations. Two factors were extracted by means of a principal factor analysis.

The first factor was identified as 'perceptual speed'. This was consistent with previous findings (Grant & Schepers, 1969), and was, according to Grant (1970a) consistent with the terminology in the literature (French, 1951). The second factor was labelled 'perception of form relations' which Grant (1970a) asserted corresponded with the Vz factor of Michael et al. (1957), the major difference between the two factors being due to the nature of the tests (performance versus pencil-and-paper). M.A. Verster (1976), however, criticized Grant's (1970a) methodology and interpretation of the two factors. According to her, Grant's (1970a) interpretation of 'perceptual speed' was determined by the loadings of the two sorting tests, but did not take into account the emphasis on learning and generous time limits for Cube Construction and Tripod Assembly Tests; 'perception of form relations', furthermore, was referenced by five tests of similar format, whereas factors should be determined by at least three measures differing in format but requiring the same mental operation.

Ballentine (1982) also criticized Grant's (1970a) interpretation of 'perceptual speed'. He contended that this factor is actually Thurstone's (1949) first space factor, particularly if the parts of the Circles Test are taken as separate problems. He also contended that one could just as well view the Pattern Reproduction Test in a similar way, and that its loading on the perceptual speed factor (although low) supports his contention that the factor might indeed be S_1. Ballentine (1982) stressed that one of the main reasons that only one spatial factor has been found in studies dealing with Blacks is due to there being a limited range of tests available in order to overdetermine adequately the various spatial factors. Given additional suitable tests, the spatial structure of African Blacks should become clearer. Accordingly, in order to test Thurstone's (1949) three spatial factors, he adapted Thurstone's (1938) Hands Test and constructed a 97-item Hands Comparison Test, which he administered to 180 Black mineworkers with six or more years of education, together with reference tests of perceptual speed, spatial relations and visualization from the Educational Testing Service Kit (French et al., 1963). Seven factors of which five could be interpreted were extracted by means of a principal factor analysis and an oblique rotation.

Three of the factors suggested Thurstone's (1949) structures and Ballentine (1982) interpreted these as: the ability to rotate in the third dimension (S_3); the "ability to make mental transformations upon parts of a configuration where other parts remain constant" (p. 102) (S_2); and two-dimensional mental rotation (S_1). These findings appear contradictory to those of Grant (1970a) and earlier researchers (Brimble, 1963; MacDonald, 1945; Murray, 1956; Vernon, 1950), which were evidence of a rather narrow view of the intellect of African Blacks, and suggested instead to Ballentine (1982) that the structure of Black African intellect is more likely to be similar to that proposed by Thurstone (1938). What is apparent, however, is that "much more work is needed to isolate the crucial feature in peceptual tasks that create spatial difficulties for Africans" (Vernon, 1969, p. 186).

3.3.3 Difficulties with regard to the measurement of spatial perception in Blacks

That African Blacks lag behind their White peers with regard to spatial perception is a consistently noted trend in reported studies (Biesheuvel, 1949; Deregowski, 1968a, 1972a, 1976; Grant, 1970a; Heron, 1968; Jahoda, 1980b; Jahoda & McGurk, 1974; Mandler & Stein, 1977; McFie, 1961; R.J. Miller, 1973; Poole, 1969; Verhaegen & Laroche, 1958). This phenomenon has been attributed to neurological and environmental/ethnic differences. For a more detailed discussion of these difficulties and a review on the possibility of training spatial perception, see Epstein (in press).

3.3.3.1 Neurological factors

(a) Genetic differences:

Male superiority on a variety of psychomotor measures of spatial ability has been extensively reported (Anastasi, 1976; Harris, 1981; Maccoby & Jacklin, 1974; MacFarlane Smith, 1964; McGee, 1979, 1982; Shepard & Metzler, 1971; Sherman, 1967, 1978; Vandenberg & Kuse, 1979; J.M. Verster, 1982), with visualization being the most commonly reported sex difference (Harris, 1981; Jensen, 1980; Metzler & Shepard, 1974; Tapley & Bryden, 1977). Sex linkage (x-linkage) of spatial ability has been suggested as the mode of genetic transmission of sex differences in spatial ability (Bock & Kolalowski, 1973; Stafford, 1961; Yen, 1975). Jensen (1971, 1975) postulated the phenomenon of sex linkage to attempt to explain race x sex interactions with spatial and other abilities. Correlational patterns which are inconsistent with hypotheses of sex linkage have been obtained, however, on a sample of Americans of Japanese ancestry (De Freis et al., 1974) and a sample of Koreans (Park, 1975), thus Jensen's (1971, 1975) hypotheses, particularly his theory that Blacks are deficient in spatial ability, has been refuted (Stephens & Hyde, 1978).

(b) Maturation and cerebral localization:
Differential rates of functional maturation affect the development and organization of higher cortical functions, particularly cerebral lateralization (J. Levy, 1976; Maccoby & Jacklin, 1974; Waber, 1976; Witelson, 1976). Recent work on hemispheric specialization has suggested that the dominant hemisphere (that is, the left) is critical for verbal, analytical, and logical skills, while the non-dominant side (the right side) is specialized for global, intuitive, and spatial processing (McGee, 1979, 1982; Sperry, 1968; Vandenberg & Kuse, 1979; Waber, 1976; Witelson, 1976); and that males have greater hemispheric specialisation than females (Harris, 1981; McGee, 1979; Witelson, 1976). Overall performance on spatial tests has been shown to be positively related to the extent to which there is lateral separation or specialization of functions (Harris, 1981; J. Levy, 1976; Zoccolotti & Oltman, 1978). 'Well-lateralized' individuals should thus be superior in spatial ability to those 'less well-lateralized', whether they are male or female.

3.3.3.2 <u>Environmental determinants</u>
Biesheuvel (1972) believed that the main cause of perceptual differences pertains to environmental factors which are very difficult to disentangle. This is perhaps the reason that recent workers (Grant, 1970a; Irvine, 1969a) have abandoned comparisons of performance measures as such, concentrating rather on examining the varying factorial patterns of abilities in different cultures.

(a) Differential socialization:
Sex-related differences in spatial ability are thought to arise from differential sex-role practice which is shaped by culturally determined sex-role patterns of behaviour. The cultural sex-typing thus provides males with more opportunities to practise spatial skills

and to acquire superior manipulative abilities, which then generalize to other spatial tasks (Kagan & Kogan, 1970; Maccoby & Jacklin, 1974; Sherman, 1978; Vandenberg & Kuse, 1979; Witkin, 1967; Wittig & Petersen, 1979). Although Sherman's (1967) bent-twig hypothesis enjoys wide support, it has been extensively criticized. Jahoda (1979, 1980b) has made the point that most of the evidence comes from Western industrial cultures and thus is not applicable to all, and Harris (1981) has stated that the available evidence on differential socialization is inconclusive and insufficient, and that the origin of sex differences may instead be in endogenous variables.

(b) Lack of early visual kinaesthetic experience:
The importance of experiential factors in the development of spatial skills has been suggested by Berry (1966) and Vernon (1966). The relative lack for rural Africans of visual kinaesthetic experiences from infancy could be a major factor which could account for the differences in spatial abilities and field dependence observed between Temne Africans and Eskimos (Berry, 1966). Both groups lack contact with pictorial matter, yet the Eskimos have considerable pictorial and mechanical aptitude (Deregowski, 1980) and are relatively field independent. The Eskimos need to travel extensively over land and sea and to orientate themselves in relatively featureless areas. They have to learn to pick out seemingly minor variations from a generally monotonous and barren environment. The Temne, however, need not develop comparable disembedding skills as they live in a highly differentiated environment.

(c) Carpentered versus uncarpentered environment:
Western groups are typically exposed to angular shapes, whilst others, such as the traditional Zulu culture, emphasize roundness. The environmental distinctions have been studied in relation to susceptibility to illusions (Cole & Scribner, 1974; Smith, 1973), and could be related to the development of such spatial concepts as Cartesian co-ordinate systems (Liben, 1981).

(d) Formal and informal education:

It has been found in a number of studies in developing countries (Crawford-Nutt, 1977a, 1977b; Grant, 1969; Mauer, 1974; McFie, 1961; Schepers, 1974; Silvey, 1963; T. Taylor, 1977) that level of education facilitates performance on various ability tests. This level of formal and informal education has been found to be related to the ability to interpret drawings three-dimensionally (Dickinson, 1980; Hudson, 1960; Kilbride & Robbins, 1968; McFie, 1961; Mundy-Castle, 1966; Serpell, 1979).

Hudson (1960) in his study on depth perception, showed that with respect to his White sub-samples three-dimensional perception was associated with both educational level and intelligence. With respect to his Black sub-samples this was not the case. According to Hudson (1960), for Blacks and for an inbred and isolated White community, the critical variable for depth perception was adequate exposure to the appropriate experience (informal education during the formative period).

> Western culture is book-learned, characterized by dependence upon the written word, illustration, diagram, photograph. Visual presentation is a common mode in the classroom, in the factory, and on the hoardings. Educational and training programmes, advertisements, safety and health propaganda, and much current didactic literature make use of pictorial material. Certain characteristic habits have become normal for Western culture and for the groups professing it. Pictorial representation of a three-dimensional scene requires the observance and acceptance of certain artistic or graphic conventions. Pictorial depth perception depends upon response to these conventional cues in the two-dimensional representation. (Hudson, 1960, p. 185)

Thus, according to Hudson (1960, 1962), education does not play a decisive role in the development of spatial perception but is subordinate to cultural and environmental factors. Although Hudson has been extensively criticized on many methodological grounds (Hagen, 1974; Hagen & Jones, 1978; Jahoda & McGurk, 1974; Leach, 1977; Omari & Cook, 1972; Omari & MacGinitie, 1974) so that his findings should, perhaps, be generalized with caution, the essential findings have been well supported by more recent studies (Perkins & Deregowski, 1982; Serpell & Deregowski, 1980).

Numerous writers (Biesheuvel, 1943, 1949, 1952b; Deregowski, 1968b, 1972b, 1974; Hagen & Jones, 1978; Jahoda, 1956; Kilbride & Robbins, 1967; R.J. Miller, 1973; Mundy-Castle, 1966; Omari & MacGinitie, 1974; Smith, 1973; Stacey, 1969) have demonstrated the role of culture in influencing and shaping depth perception and pictorial recognition. Biesheuvel (1952b) attributed the so-called inferiority of Blacks in manipulating spatial relations to a lack of familiarity with the

> conventional spatial arrangements which are an essential part of our daily activities (block games, arrangements of furniture, positioning of pictures on walls, laying of the table, layout of reading matter) etc. (p. 53)

Thus level of acculturation has been shown to be positively related to depth perception in accordance with Hudson's (1960, 1962, 1967) theory (Deregowski, 1970; Omari & MacGinitie, 1974) and to susceptibility to illusion (Smith, 1973). This is in accord with Selden (1971) who has suggested that a person sees what his culture has trained him to see. Urban children are constantly exposed to books, magazines, television, the cinema, and to the complexity of a modern technological environment which they accept as a part of everyday life. Selden (1971) made the point that the keenly developed ability of the urban child to interpret pictures should not be assumed to be natural ability. Many other researchers (Abiola, 1967; Berry, 1971a; Biesheuvel, 1952b; Hendrikz, 1975; Kilbride & Robbins, 1967; R.J. Miller, 1973; Van der Reis, 1967) have confirmed that pictorial perceptual skills are positively and significantly related to exposure to Western culture.

According to Berry (1971a, 1971b), spatial perceptual development is considered to be a function of ecological demands mediated by culture, and he demonstrated that

> the psychological underpinnings of technological development, often stated as spatial ability, are shown to develop in relation to an ecology which by way of technological change is open to change itself. (Berry, 1971a, p. 331)

However, this assumption may be open to question as many of the tests which Berry (1971a) classified as spatial, that is, Koh's Blocks, an embedded figures test, and Raven's matrices, are rather, where illiterate and semi-literate Africans are concerned, measures of 'g' (Grant, 1970a; Vernon, 1969).

(e) Personality differences:
Psychological differentiation, particularly as manifested by the concepts of field dependence/field independence has been shown to be related to spatial ability (Dawson, 1967a, 1967b; Gardner, Jackson, & Messick, 1960; Hendrikz, 1975; Horn, 1976; Sherman, 1967; J.M. Taylor, 1980; Vernon, 1969; Witkin, Dyk, Faterson, Goodenough, & Karp, 1962).

Witkin (1967) has defined the field dependent person as one who orientates himself by reference to the environment, has global perception and who has a greater need to function as a member of a group. People who are conforming and field dependent tend not to be open to new experiences -- they thus seem to learn to use depth cues more slowly or with more difficulty than those individuals who are less conforming, field independent and who are more open to new experience (Dawson, 1967a). Females tend to be more field dependent, whilst males tend to be more analytical and field independent (Witkin et al., 1962).

The development of field independence has been attributed to socialization practices (Dawson, 1967a, 1967b; Smith, 1971; Witkin, 1967; Witkin & Berry, 1975); to urbanization (Okonji, 1969); and to ecological environmental factors (Berry, 1966, 1971a; Vernon, 1969). Thus a relatively field dependent cognitive style is likely to be prevalent in social settings characterized by insistence on adherence to authority figures and by utilization of strict socialization practices (Dawson, 1967a, 1967b; Witkin, 1967; Witkin & Berry, 1975).

Schwitzgebel (1962) compared Afrikaans and Zulu males on measures of field dependence. The Afrikaners were significantly faster at disembedding tasks than the Zulus ($p < 0{,}001$) and he concluded that specific perceptual organizations are culturally determined and environmentally dependent.

(f) Nature of the task:
African art is essentially volumetric (Hudson, 1960) and sculpture and pottery flourish in Africa. African children fashion intricate and complicated wire toys (Biesheuvel, 1979; Dickinson, 1980; Serpell, 1979; Thomson, 1967, 1972). It is thus possible that Africans do not have a general disability with regard to spatial perception but that their difficulty would depend on the nature of the perceptual task involved.

The results of a study conducted by Jahoda (1979, 1980b) comparing Ghanaian and Scottish schoolchildren on a variety of tasks are indications that spatial ability is not homogeneous, and that ethnic and sex differences are probably related to the nature of the task. Jahoda (1980b) has suggested that this would account for the many inconsistencies and contradictions which abound in the literature.

On a task which involved the encoding of three-dimensional objects under memory conditions, Jahoda (1979) found a typically sex-related difference; males in Ghana and in Scotland were superior to the females in both cases. However, while the Ghanaians performed on the same level as the Scots when they had to work from a model, they experienced difficulty ($\underline{p} < 0{,}001$) when they had to work from line drawings or photographs. The difficulty thus did not appear to be an encoding problem but rather one of extracting the relevant information from a two-dimensional drawing.

This result is in agreement with Kennedy (1974) who could find no evidence for cultural differences in picture perception, but considerable evidence that it is the interpretation of the meaning or importance of the various aspects of the pictures which is strongly influenced by culture.

On two tasks involving rotation of shapes, the Ghanaian children again experienced more difficulty ($\underline{p} < 0{,}001$) when mental rotation of the shapes was required than when allowed physically to rotate the shapes (Jahoda, 1979, 1980b). Thus it appears that mental rotation is an important source of spatial difficulty in African children. Mandler and Stein (1977) came to a similar conclusion.

Jahoda's (1979, 1980b) studies tend to refute Sherman's (1967) differential socialization theory, as Jahoda (1979, 1980b) found the same pattern of differences between boys and girls in both countries. The Ghanaian children came from a rural farming village, while the Scottish children lived in an industrial suburb of Glasgow. Given these two very different contrasting cultures, it would be unlikely that common elements of differential socialization would be prevalent.

3.3.4 Development of spatial perception

(a) Developmental perspective

According to Piaget and Inhelder (1948) the development of the concept of space is neither innate nor learned. Rather, it is constructed by the child as a series of hierarchically integrated equilibrations through an adaptive interaction with the environment and by means of the reciprocal processes of assimilation and accommodation. The understanding of space is thus more than the learning or mere accumulation of facts. It is an active manipulation of the environment where actions rather than perceptions account for the development of spatial cognition.

(b) Problem-solving and information-processing:

The results of cross-cultural studies in Africa on visual perception are indications that there are persistent and significant differences in the manner in which pictorial information is interpreted by people of different cultures, and that this perception calls for some form of learning and the acquisition of habits of perceptual inference (Deregowski, 1972a; Hebb, 1949; Hudson, 1960; Jahoda, 1956; Segall, Campbell, & Herskovits, 1963; Selden, 1971).

> Visual perception is a continual problem-solving process. It relies upon the active searching for the best interpretation and meaning of sensory information. The act of perception of line patterns may be considered as a decision, based on the information selected from the display of lines,

> about the 'real' nature of the display. This information is received and identified by means of cues (or clues), some existing in the line patterns, others inherent in the observer by virtue of his knowledge, experience and memory. A vital feature of visual perception is that it always goes beyond immediately available information. The personal history stored within the brain has to give meaning to the sensory signals it receives. If the pictorial information is new or unusual, then misperception may occur and we may see wrongly. (Davies, 1976, p. 4)

The information-processing and problem-solving approach in spatial perception has support in the literature (Deregowski, 1980; Ekstrom et al., 1976; Gregory, 1970; Turvey, 1978), and according to Deregowski (1980, p. 37), a difference between the responses of two groups of subjects on any perceptual task can be attributed to:

- difference in initial tentative hypothesis;
- ease with which a hypothesis is evaluated;
- ease with which a new hypothesis is substituted for an abandoned hypothesis;
- rate at which successive hypotheses approach 'correct' perception.

This problem-solving approach would thus imply that there may be a link between spatial perception and analytic thinking. Thus Kemp (1980) has reported that spatial perception abilities are relevant in analytical subjects where imagination and initiative are required, and Brohn and Cowan (1977) have demonstrated a positive relationship between spatial ability and achievement in structural engineering.

If these observations are taken into account, difficulties in understanding and processing information presented diagrammatically may be related to difficulties in processing and integrating other novel information, thus suggesting that there are fundamental problem-solving abilities which have not been adequately developed.

3.4 Effect of culture on the structure of mechanical aptitude

Mechanical aptitude has been found to be a component of several abilities in Western groups, encompassing general intelligence, spatial ability, mechanical information and experience, and relevant manual dexterity and motor skills (Vernon, 1950). It is a construct which has developed within a technologically sophisticated culture, and it is likely that the structures found in one culture will not necessarily be found in other cultures (Ferguson, 1954, 1956).

Bowd (1973) accordingly studied Canadian-Indian and Metis boys aged between 12 and 14 years from four cultural groups, together with a sample of White boys of a similar age from Calgary. He administered tests of spatial ability, mechanical knowledge, dexterity and co-ordination, together with non-verbal tests of abstract reasoning, vocabulary, and a background questionnaire.

The factor matrix of the pooled data was rotated and six orthogonal factors were extracted: 'g', verbal, background, dexterity, age, and activities. The first factor, 'g', was rather more spatially and mechanically loaded than the usual general reasoning ability factor. Bowd (1973) interpreted the 'verbal' factor as verbal skill which is mediated by facility in English.

Factor scores estimated for all subjects using the total group means and standard deviation were separated for each group, and the mean and standard deviation for each of these samples were calculated. An analysis of variance comparing the factor means showed significant between-groups differences for all factors except 'g', with the 'verbal' factor showing the largest variation ($F = 45,10$; $p < 0,01$). The general lack of factorial congruence led Bowd (1973) to the conclusion "that 'mechanical aptitude' is of varying composition for groups of different cultural environments" (p .21).

Although Bowd (1973) asserted that amongst the diverse groups, Indian and Metis boys showed mechanical ability comparable with that of White urban children, he suggested that extrinsic differences found in the verbal factor, together with its high correlations with language and socio-economic variables, are indications that the achievement differences obtained for the White children stemmed from their environment and are mediated to a large extent by facility in English.

Bowd (1973) sounded a cautionary note which would appear to be particularly relevant to the South African situation:

> It is not the writer's purpose to argue for mechanical aptitude as a psychological universal, or to argue that environmental conditions relating to it may be analysed in terms of cultural universals. Rather it is proposed that, in order for the individual to adapt and to function successfully within a society becoming rapidly more sophisticated technologically, certain abilities are essential. Obviously, a kind of 'intelligence' that includes the manipulation of abstract numerical and verbal symbols is a pre-requisite. Similarly, given that 'mechanical aptitude' is a culture-bound concept, the kind of abilities it entails must be developed if the individual is to perform successfully in occupations involving the use of tools and machinery. (p. 14)

3.5 Biographical influences on mechanical aptitude

3.5.1 Validity studies

In the light of the aforegoing discussion on the role of culture in the differentiation of ability, an examination of the relationship between biographical data and mechanical aptitude would be germane. Personal background information about the individual in a variety of forms has been used for almost a century to predict a large spectrum of human behaviour, including interests, attitudes, abilities, personality characteristics and performance. This is demonstrated in Owen's (1976) comprehensive review of biographical data. Indeed, Biesheuvel (1962) noted that biographical inventories which record factual details concerning the individual's life history, including his family background, his educational and occupational records, his interests, and his social and leadership activities, are a common feature in most selection programmes. Asher (1972), in a review of studies concerning the weighted application blank, concluded that biographical information shows substantially higher predictive validity against a job proficiency criterion than other predictors including tests of intelligence, personality, interest, perception, motor skills and mechanical ability. The general conclusion reached by Asher (1972) is that factual and verifiable historical information is the best predictor of future performance. Other writers (Ghiselli, 1966; Lätti, 1972) have provided corroborative evidence to support the contention that past performance is the best predictor of future performance.

Baehr (1978) reported that biographical data instruments can be used to predict success in a variety of occupations, but that the pattern of background factors predicting performance is specific for each occupation. Bearing this in mind:

> Common sense would seem to tell us that hobbies and ability both present and future are, to some extent, linked: thus the boy who is interested in using his hands and acquiring some degree of practical information and skill in his spare time -- the one who has many constructional and meccano-like hobbies (all else being equal) is more likely to reach a higher level ... at the workbench than his fellow who spends more of his spare time following other pursuits. (Ross, 1962, p. 69)

The links between mechanical hobbies and interests on the one hand, and mechanical aptitude on the other have been noted by many observers with some equivocal results. Significant correlations between biographical information relating to previous experience in mechanical activities, and criteria of on-the-job success in mechanical jobs have been reported by a number of researchers (Ekvall 1969; Fruchter, 1952b; Guilford & Lacy, 1947; Paterson et al., 1930; Sorenson, 1966). In similar vein, significant correlations between hobbies of a mechanical nature and success on mechanical criteria (Guilford & Lacy, 1947; Henry, 1965; Mottram, 1977; Pendelbury & Hardman, 1967), and between mechanical hobbies and spatial visualization ability (Blade & Watson, 1955; Kemp, 1980; Pendelbury & Hardman, 1967), and mechanical comprehension (Kemp, 1980; Ross, 1962) have been reported. Indeed, an interesting point came from Henry (1965, p. 913), whose question "Did you ever build a model airplane that flew?" was almost as good a predictor of success in flight training during World War Two as the entire Air Force Battery!

However, some evidence refuting a relationship between hobbies and mechanical success (McMahon, 1962; Ross, 1962), hobbies and engineering drawing (J.M. Taylor, 1980), and hobbies and cognitive test scores (Mottram, 1977; Pendelbury & Hardman, 1967) has been reported. MacFarlane Smith (1964) stated that "little reliance should be placed on assessment of interest in hobbies for the long term prediction of success in theory or practical skills in engineering" (p. 148).

Sorenson (1966), however, contended that results from his Background Survey Questionnaire, which correlated significantly (r = 0,30, p < 0,01) with a criterion of on-the-job mechanical success, were supportive of his hypothesis that a good mechanic is 'born' rather than 'made', and he found that the "better mechanics appeared to rely on mechanical intuition and experience rather than formally taught principles" (1966, p. 351).

3.5.2 Factor studies

French (1951) has identified a 'mechanical experience' factor which involves knowledge of mechanical apparatus principles rather than an innate ability to be a mechanic. According to French (1951), tests which load highly on this factor include tests of mechanical principles, routine assembly, knowledge of tools, biographical data and general information, particularly questionnaires which examine the relationship of hobbies and experience. Mechanical comprehension tests tend to be determined partly by mechanical experience, partly by elementary training in physics, and partly by the intuitive understanding of mechanical problems (Sorenson, 1966; Thurstone, 1949). An interesting point was made by French (1951) that in the factor analyses where motor and mechanical skills were used as variables, no factor of mechanical ability appeared. This serves to confirm that "mechanical ability represents some combination of factors rather than a unitary ability" (French, 1951, p. 223).

Many researchers have reported that biographical information loads on mechanical factors (Bowd, 1973; Dudek, 1948; Ekvall, 1969; Friedman & Detter, 1975; Friedman & Ivens, 1967; Fruchter, 1952b; Guilford & Lacy, 1947; Guilford & Zimmerman, 1947). Guilford (1948) asserted that the only distinctive element in any mechanical test, apart from spatial and dexterity factors, is one of information.

Fruchter (1952b) found that a biographical inventory loaded on a mechanical experience factor of the Army Air Crew Classification Test Battery, which had high correlations with final course grade criteria of aircraft sheetmetal workers ($\underline{r}$ = 0,39); draftsmen ($\underline{r}$ = 0,54); electricians ($\underline{r}$ = 0,56); airplane and engine mechanics ($\underline{r}$ = 0,74).

Tests loading on mechanical experience factors have mechanical content together with familiarity with tools and thus will be culturally determined (Guilford & Zimmerman, 1947). The corroborative evidence for this was given by Bowd (1973) in his cross-cultural investigations of mechanical aptitude. He found that a biographical background questionnaire loaded on two factors: 'mechanical activities' and 'background'. 'Mechanical activities' was most clearly distinguished by high loadings on ownership of a bicycle (0,42) and presence of mechanical hobbies (0,72), and 'background' had high loadings on reading of mechanical magazines (0,61) and knowing someone mechanically skilled (0,62). However, Bowd (1973) noted that several variables loaded on both the 'mechanical activities' and 'background' factors and thus his naming of the factors was essentially conjectural. Bowd (1973) found that the inventory could predict mechanical ability successfully and that the urban sample was clearly superior in all of the activities. Dudek (1948) analysed and compared factors obtained from the United States Army Air Force Air Crew Classification Battery administered to a group of Women's Auxiliary Service Pilots in flight training and male pilots in training. Five factors were common to both groups, the notable exception pertaining to a mechanical knowledge factor obtained for the male pilot trainees but not for the women. This was clearly attributable, according to Dudek (1948), to the fact that the women's mean and standard deviation scores in the 'mechanical knowledge' factor were distinctly lower than the men's. The women were a highly select group and hence the female 'culture' did not introduce variance with respect to mechanical knowledge that the males had to differing degrees.

3.5.3 Biographical inventories with regard to Blacks

Little work has been done on biographical inventories suited to African conditions, mainly because of the low levels of literacy which have prevailed. One biographical item which has consistently been related to performance is, however, educational level (Crawford-Nutt, 1977a; Grant, 1969; Irvine, 1969a; McFie, 1961; Mauer, 1974; Schepers, 1974). Biesheuvel (1962) commented that the construction of biographical inventories in Africa cannot be approached conventionally. "Items must be re-formulated to fit the cultural characteristics of the particular group with which it is concerned" (p. 140). He warned that whereas these problems are less acute when educated and urbanised Africans are being dealt with, they do not disappear altogether,

> ... because all African societies, even those that have been most profoundly changed by their contacts with the West, possess characteristic features that are reflected in the personalities that develop within them. (Biesheuvel, 1962, p. 140)

Basing his biographical inventory on Bowd's (1973) work in Canada, Botha (1976, 1978) obtained a significant correlation (n = 354, r = 0,49) between the inventory and a criterion of on-the-job success for Black workers in relatively high level technical and mechanical jobs. According to Botha (1976) ten items discriminated: age, school qualification, previous job, owning a camera, father's occupation, school subject preferred, ability to drive a car, father's owning a bicycle, having tools at home, and owning a car. However, these results should be interpreted with caution as anomalies are apparent with regard to the last three items, as a higher proportion of those answering in the affirmative were in groups scoring low on the criterion (that is, they are weighted negatively).

Kemp (1980) reported that Black students who did well on tests of mechanical reasoning and space relations had technical interests and experience in the field.

3.6 Interest inventories

3.6.1 Influence of interests on mechanical aptitude

Results of the research on the validity and utility of interest inventories have been equivocal. Guilford and Lacy (1947) suggested that because interest inventories sample interest and appreciation, their validity is low compared with biographical inventories which sample experience. Ghiselli and Barthol (1953), and Ghiselli (1966) found that whereas tests of intellectual abilities, particularly spatial and mechanical, accurately predict success in mechanical jobs, interest inventories appear to have little validity. Some writers, however, (Long & Perry, 1953; Super & Crites, 1962) have suggested that interest inventories may be useful adjuncts when used together with a test battery. Others (Gouws, 1966; Strong, 1945; Van Tonder, 1977) have stressed that interest as a variable cannot be a valid predictor of success because the relationship between interests and the criterion is often very complex. However, in an analysis of 8 214 school pupils' reasons for choosing a career, interest emerged as the strongest consideration (Garbers & Van Aarde, 1974).

Relationships between expressed interest and mechanical aptitude have been demonstrated by several authors (Estes & Horn, 1939; Paterson et al., 1930; Strong, 1945; Super, 1949; Thurstone, 1950, 1951). In the Minnesota Project (Paterson et al., 1930), an interest analysis blank was significantly correlated (r = 0,55, p < 0,005) with a quality criterion. Thurstone (1951) in his study of mechanical aptitude, selected two groups on the basis of a high or low rating on the Mechanical Interest scale of the Kuder Preference Record (Kuder, 1939) and high or low scores on criterion tests of mechanical experience and comprehension. In addition to the Mechanical Interest rating on which they were selected, the 'high' group rated themselves significantly higher on the Scientific (t = 2,9, p < 0,005), Clerical (t = 2,6, p < 0,005) and Artistic (t = 1,9, p < 0,05) categories, and significantly lower on the Musical (t = 3,4, p < 0,005), Literary (t = 3,0, p < 0,005) and Persuasive (t = 2,2, p < 0,01) categories. Thus, according to Thurstone (1951, p. 25) "it looks, therefore, as if people with mechanical aptitude and interests are not ordinarily found among socially outgoing people or among those with strong literary or musical interests." Möller (1965), however, reported a negative correlation between mechanical interests and academic achievement in engineering, and Garbers and Faure (1972) noted that measures of interest are poor predictors of academic success.

A number of writers (Arbuthnot & Gruenfeld, 1969; Barrett & Bass, 1972; Gruenfeld & MacEachron, 1975; Holtzman, Swartz, & Thorpe, 1971; S. Levy, 1969; Zytowski, Mills, & Paepe, 1969) have noted that occupational interest choices are related to field dependence. People who are more field independent tend to pursue occupations such as mechanical ones which require analytical cognitive skills, rather than pursuing more 'people-oriented' occupations.

3.6.2 Interest inventories for Blacks

The difficulties and limitations inherent in using interest inventories for Blacks have been well noted (Biesheuvel, 1962; Carter, 1980; Chansky, 1967). Indeed, Biesheuvel (1962) cautioned that:

> A probable limitation in the use of all interest tests in Africa is that they are likely to be influenced by currently fashionable value judgments, and by unduly optimistic and unrealistic ambitions of people on the threshold of new occupational opportunities. In Western societies with established economies there is ... some relationship between socio-economic status and the choice of a career. There is as yet little of this in Africa, and professional and clerical occupations may be chosen not because they are within the individual's reach, or because he has an intrinsic interest in them, but mainly because they confer social status. (pp. 148-149)

The unrealistic nature of vocational aspirations of Blacks in Africa which Biesheuvel (1962) mentioned has been confirmed by numerous writers (Breger, 1976; Cloete, 1981; Erwee, 1981; Hall, 1978, 1980; Mojalefa, 1980; Obanya, 1978; Shannon, 1975; Spence, 1982; Tunmer, 1972; Visser, 1978). It has been found in numerous studies in South Africa (Breger, 1976; Cloete, 1981; Erwee, 1981; Hall, 1978, 1980; Shannon, 1975; Spence, 1982; Tunmer, 1972; Visser, 1978) that Blacks consistently indicate a preference for the medical and social service fields and show a strong dislike for the outdoor, practical and mechanical fields.

The occupational expectancies of Black students are incongruent with labour market reality, as one of the biggest projected demands for

Blacks is in technological occupations (Cloete, 1981; Sadie, 1981; Vermaak & Terblanche, 1976; Visser, 1982). An inverse relationship has thus been observed in that whereas the majority of job opportunities are at the skilled level, the expectations of the Blacks are directed toward the professions (Biesheuvel, 1962; Breger, 1976; Cloete, 1981; Tunmer, 1972; Visser, 1982). This observed predilection for the professions is consistent with data from researchers in other developing countries (Abiri, 1977; Clignet & Foster, 1966; Klingelhofer, 1967).

Whereas the occupational orientation of American Blacks has a certain resemblance to the job distributions in the labour market (Gottfredson, Holland & Gottfredeson, 1975), the avoidance of scientific and technological occupations by Blacks in America has been noted (Bayer, 1972; Sewell & Martin, 1976). This applies to Blacks in other African countries (Blay, 1973), as well as South Africa. Marked differences with respect to Nigerians, however, have been found, substantial numbers of whom expect to enter technical occupations (Cloete, 1981). Cloete (1981) has stated that this observed lack of interest in technical occupations is consistent with the stereotype that Blacks are 'people' rather than 'thing' orientated (Bayer, 1972) which may provide an explanation for their preference for social service occupations. Godsell (1982), however, has stated that in the South African context, the need to be of service is internalized in the Black value system as the concept of 'ubuntu' which is a central value prescribing their behaviour towards others.

Visser (1978) ascribed her findings with regard to the disfavour with which the practical, outdoor and mechanical fields were viewed, as being due partly to their manual labour implications, and partly to their non-academic and hence their low-status connotations. Indeed, Cloete (1981) demonstrated that the occupation of mechanic was preferred by only 0,26% of his sample, and that the popularity of technical and scientific occupations appeared to decrease from Standard 8 to first year university.

The vocational choices of Blacks appear thus to be affected by influences other than those which affect Whites. Some of the contributory causes which narrow the occupational interests of young Blacks include lack of occupational knowledge (Mojalefa, 1980; Williams, 1979) and need to take discriminatory practices into account (Biesheuvel, 1974; Cloete, 1981; Crites, 1969; Picou & Campbell, 1975).

3.7 Structure of mechanical aptitude with regard to Blacks

Whereas many studies have been conducted into the structure of intellect (Biesheuvel, 1954; Grant, 1969; Grant & Schepers, 1969; Kendall, 1971; MacDonald, 1945; Murray, 1956; Vernon, 1950) and spatial abilities (Ballentine, 1982; Grant, 1970a) of illiterate and semi-literate Blacks, there has been a paucity of research into the factors related to mechanical aptitude per se. As far as can be ascertained, no studies investigating the factors pertaining to mechanical aptitude of Blacks with higher levels of education in Southern Africa have been conducted to date.

The reasons for this stem primarily from the fact that until recently the majority of the Black work force has been engaged in mainly low-level mechanical tasks at operator level or below, requiring little initiative and few decision-making skills. The sample available for research has been mainly illiterate or semi-literate, with all the concomitant difficulties with regard to psychological testing in developing groups which many writers have discussed at length. These include:

- conceptual incompatibility (Berry, 1971b; Biesheuvel, 1949, 1952b, 1952c, 1958; Faverge & Falmagne, 1962; Hudson, 1960; Irvine, 1963, 1969a, 1969b; Poortinga, 1971; Vernon, 1965).

- tests tending to measure acculturation and familiarity with Western modes of thought rather than aptitudes (Faverge & Falmagne, 1962; Ombredane & Faverge, 1955; Vernon, 1965).

- tests measuring different concepts depending on educational level and subsequent differentiation of ability (Crawford-Nutt, 1977a; Grant, 1970a; Irvine, 1969b).

- the misnomer of the 'culture-free' test (Biesheuvel, 1952c, 1958; Irvine, 1969b; Jahoda, 1956; Serpell, 1974; Silvey, 1963; Verhaegen & Laroche, 1958; Vernon, 1965).

Many researchers (Heron, 1966; Irvine, 1962, 1963, 1969a; Irvine & Carroll, 1980; Jahoda, 1956; Lloyd & Pidgeon, 1961; Ombredane, Robaye & Plumail, 1956; Schepers, 1974; Silvey, 1963; Verhaegen & Laroche, 1958; M.A. Verster, 1976; Von Mollendorf, 1974) have pointed out that test scores of African subjects are clearly a function of education and practice and are thus liable to significant increases with practice and coaching. This invariance of test scores applies particularly to non-verbal, figural constructs.

The little that is known about the mechanical aptitude of Blacks tends to be of a rather equivocal nature. Vernon (1950) remarked on the 'retarded' development of the practical intelligence of the Blacks, and Biesheuvel (1961b, p. 28) has stated that Africans are known to suffer "considerable cultural handicaps" in thinking in three dimensions, whereas Cryns (1962, p. 296), writing in the following year, reported that investigators have ignored the African's "phenomenal sense of spatial orientation" and his "superior psychomotor behaviour". Biesheuvel (1963) noted that rural Blacks have little opportunity for manipulating and using mechanical devices, yet commented later (Biesheuvel, 1979, p. 289) on the "complicated ... mechanical devices" which they make.

The conclusions regarding the factor structure of Blacks have been equally confusing and contradictory. Murray's (1956) assertion regarding the African's simplicity of mental structure may be contrasted with that of J.M. Verster (1982, p. 378) who offered evidence pointing to a complicated model of cognitive processes which has "universal validity in normal adult populations, regardless of difference in racio-cultural variables", and El-Abd (1970) and

Durojaiye (1971) who demonstrated that the structure of intelligence is independent of race.

One of the problems caused by the cultural differences between Blacks and other Western groups is that there are a limited variety of tests available for studying the cognitive structure of Blacks (Ballentine, 1982). In order to determine a factor adequately at least three tests, differing in format but requiring the same operation, loading on that dimension are required. If only two tests load it is not possible to obtain unique estimates of communality (Grant & Schepers, 1969). Due to the low levels of literacy prevailing among the Blacks, most of the tests used in the past were of the performance type, like the General Adaptability Battery (Biesheuvel, 1952a, 1954) and the Classification Test Battery (Grant, 1970b), and thus, according to Grant (1969) the whole range of abilities could not be adequately sampled. Grant and Schepers (1969) aptly described the findings of unitary factors obtained for Blacks as "more descriptive of the status of test development than of the structure of intellect" (p. 181).

With the increasing numbers of Blacks who are matriculating (Lätti, Visser, Hall, Makaula, Raubenheimer, & Tabane, 1980; Reynders, 1981) together with the recommendations of the Wiehahn Commission (Bendix, 1979) for lifting restraints on Black workers from entering skilled jobs, a more highly educated and urbanized Black population is available on which research into mechanical aptitude can fruitfully be undertaken.

3.8 Components of mechanical aptitude

3.8.1 Conceptual reasoning

A general reasoning factor has been shown to be an important component of mechanical aptitude (Bingham, 1937; McCormick & Tiffin, 1975; Patterson, 1956; Theunissen, 1979; Thurstone, 1949, 1950, 1951). A recurring theme in the literature has been that there are cultural differences in abilities and that Africans think concretely whereas Whites think abstractly and conceptually (Carothers, 1953; Cryns, 1962; Fick, 1939; Porteus, 1937; T. Taylor, 1977; Van der Reis, 1969; Werbeloff & Taylor, 1982; Wintringer, 1955). Biesheuvel (1949) believed that the poor performance of Blacks on tests of abstract reasoning is not a valid assessment of their ability to think abstractly and conceptually because "there is ample evidence that within their own cultural context they are able to do all these things" (p. 98). Some support for this came from Okonji (1971) and Price-Williams (1962). Other researchers (Du Toit, 1965; Evans, 1973; Okonji, 1971; Reuning, 1972) have indicated that the systems of classification used by rural Blacks might be quite different from those used by a White culture.

In an analysis of an extended version of the Form Series Test, Kendall (1974, 1977) found evidence to suggest that most Africans tend to adopt a perceptual rather than a conceptual strategy to solve the items. It is only with regard to the more literate Africans that there is evidence to suggest that they adopt a conceptual strategy to solve more difficult out-of-phase problems which cannot be solved perceptually. T. Taylor (1977) and Kendall (1974) have expressed their belief that the 'conceptual reasoning' factor postulated by Grant (1972) does not refer to conceptual reasoning per se, as the version of the Form Series Test which Grant (1972) used has no difficult out-of-phase items. Kendall (1974, 1977) asserted that Blacks find it difficult to shift from a perceptual non-conceptual approach to problem-solving to adopting conceptual strategies; and attributed the difficulties to socio-cultural and temperamental reasons. Irvine (1969b) has also demonstrated these differences in problem-solving strategies and noted that test scores approach Western patterns as groups become acculturated.

Indeed, many others have shown that formal education and Westernization are the media through which Blacks acquire abstract conceptual strategies (Brimble, 1963; Crawford-Nutt, 1977a; Erwee, 1981; Evans, 1973; Jahoda, 1956; Kendall, 1974, 1977; Okonji, 1971; Pick, 1980; Reuning, 1972; Schmidt, 1960; T. Taylor, 1977; Vernon, 1967; Werbeloff & Taylor, 1982). Thus depending on the quality and quantity of urbanization and formal education, literate Blacks will be able to shift from a concrete to a conceptual mode of reasoning.

T. Taylor (1977, p. 33), however, pointed out that whereas the evidence suggests that the "African culture is biased towards a concrete, perceptual mode of functioning", this mode has functional adaptive utility and value judgements about the unfavourability of concrete thought should not be made. A concrete-perceptual mode of reasoning does, however, restrict effective functioning in the Western technological environment. Higher-level technical and mechanical jobs place demands on the workers to function at the abstract-conceptual level (Kendall, 1977; T. Taylor, 1977). Technical jobs often have novel tasks which are complex and diverse and which call for flexible approaches. The individual's capacity to adapt to new situations and to new skills is thus very important. However, one of the problems pertaining to Black education is that Blacks are taught mainly by rote (Erwee, 1981; Orbell, 1975; Vernon, 1967) which tends to prevent the emergence of abstract reasoning strategies as formulated by Piaget (1946). Blacks are thus often capable of learning a great deal of theory in a mechanistic fashion (Vernon, 1967), but might experience difficulties in sifting out the relevant information (Werbeloff & Taylor, 1982); in applying the theory to the practical situation (Vernon, 1967); or in formulating decision-making strategies.

3.8.2 Perceptual factors

Apart from abstract reasoning, the likelihood exists that mechanical aptitude includes factors concerned with perceptual information processes.

Grant (1969, 1970a), Grant and Schepers (1969), and Ballentine (1982) have identified perceptual speed factors in their studies on Black mineworkers. Ballentine (1982), however, asserted that Grant's (1969, 1970a) factor of 'perceptual speed' which Grant equated with French's (1951) definition of the factor is more allied to Thurstone's (1949, 1950) S_1 factor than to perceptual speed.

Thurstone's (1949, 1950, 1951) analyses of mechanical aptitude resulted in two perceptual closure factors being extracted: speed of closure (C_1) and flexibility of closure (C_2). Tests of field independence (Thurstone, 1951) loaded on C_2.

Some writers have suggested that the concept of 'field articulation' to be a more valid description than the field independence construct (Cattell, 1971; Gardner et al., 1960; Gruenfeld & MacEachron, 1975; Pemberton, 1952) and have shown the concept to be a generalized analytical orientation related to C_2. It has been found in a number of studies (Berry, 1966; Cattell, 1971; Dawson, 1967a; Doob, 1960; MacArthur, 1968; McFie, 1961; Okonji, 1969) and in the Southern African context (Baran, 1970; Du Preez, 1968; Smith, 1971) that the analytical cognitive style and behavioural referents associated with field articulation and adaptability to industrial techniques are evident when groups in cultural transition are compared, and indicate "that this ability is associated with the occupational and educational skills relevant to an industrial and technological way of life" (Gruenfeld & MacEachron, 1975, p. 31).

Wober (1967) agreed with Biesheuvel's (1952c) comment that African cultures might foster development of skills in sensory modalities other than visual. Hence the sameness of cognitive style found in Western culture which permeates all aspects of behaviour might not occur to the same extent for Africans.

According to Cryns (1962) there is "relative unanimity" (p. 292) among researchers regarding the "incapacity" (p. 292) of Blacks for perceptual analysis, and Schwitzgebel (1962) expressed his belief that these skills might not even be attainable after extensive education. Werbeloff and Taylor (1982) attributed the low correlation ($\underline{n}$ = 72, $\underline{r}$ = 0,15) observed with a Black sample between a conceptual reasoning test and field independence, as measured by the Gottschaldt Embedded Figures Test, as being related to the holistic perceptual type of problem-solving strategy adopted by the Blacks to solve items of the Gottschaldt Embedded Figures Test. Both conceptual reasoning (Brimble, 1963; Crawford-Nutt, 1977a, 1977b; Erwee, 1981; Kendall, 1974, 1977; Reuning, 1972; T. Taylor, 1977) and field dependence (Baran, 1970; Du Preez, 1968; Smith, 1971) have been shown to be related to acculturation in Southern Africa and to be relevant for effective functioning in the Western-technological environment. It is thus likely that these factors will contribute towards mechanical aptitude.

3.8.3 Mechanical knowledge and insight

The ability to understand mechanical principles is an important component of mechanical aptitude (French, 1951; Guilford & Lacy, 1947; Guilford & Zimmerman, 1947; McCormick & Tiffin, 1975; Nunnally, 1970; Patterson, 1956; Vernon, 1961).

Sorenson (1966) indicated that often the better mechanic is one who relies on mechanical intuition and everyday technical experience rather than on formally taught principles. This would tend to place a Black, who has spent his formative years in an environment which does not feature electricity with its concomitant machinery and gadgets, at a considerable disadvantage. The complex nature of a trouble-shooting job will also place those who are unfamiliar with mechanical and technical tools at a disadvantage (Skawran et al., 1967).

Ombredane and Faverge (1955) have found that test items which employed knowledge of cues belonging to habitual graphic and diagrammatic representation of Western groups also caused difficulties among Blacks. In Vernon's (1961) factor analysis of African recruits using MacDonald's (1945) battery, a mechanical comprehension test had the poorest loadings, which Faverge and Falmagne (1962) attributed to it being the most un-African test as it contained many unfamiliar mechanical items.

The importance of previous experience and hobbies in fostering mechanical insight was pointed out by Kemp (1980) in his finding that Black students who performed well on tests of spatial and mechanical reasoning had technical interests or experience in the field. That Blacks do have an innate grasp of mechanical concepts, furthermore, is suggested by the skill with which they fashion elaborate models out of wire (Biesheuvel, 1979). Thomson (1967, 1972), too, commented that both urban and rural Black children in Rhodesia are adept at making wheeled toys from lengths of scrap wire. These range in complexity from a single wheel at the end of a steering column to replicas of the latest cars complete with draglink steering devices. Serpell (1974) also reported on the superior performance on wire modelling tasks of Zambian Black children compared with that of Whites. In fact, the

Wire Bending Test (Bennett, 1970) which has been adapted and used successfully to select Black apprentices in Zambia, loaded on a 'mechanical knowledge and experience' factor (Ekvall, 1969); and was, according to Bennett (1970), a measure of mechanical insight and experience.

3.8.4 Spatial factors

Spatial factors have been identified in many mechanical aptitude studies (Estes, 1942; Guilford et al., 1952; Guilford & Lacy, 1947; Guilford & Zimmerman, 1947; Harrell, 1940; Thurstone, 1949, 1950, 1951; Zimmerman, 1953) among Whites and in Ballentine's (1982) and Grant's (1970a) studies of spatial ability in Blacks.

Because of the importance of spatial ability for mechanical aptitude and because Blacks are known to experience difficulties in pictorial depth perception, the spatial abilities of Blacks have already been discussed in some detail (see section 3.3.2 and 3.3.3).

3.8.5 Summary

It appears from an examination of all the evidence to date that there is no clear formal model of mechanical aptitude for Whites or for Blacks. What is apparent, however, is that it is likely that the following factors play a role in the structure of mechanical aptitude in Blacks:

- spatial ability, particularly visualization;
- mechanical insight;
- conceptual reasoning;
- perceptual processing;
- mechanical hobbies;
- mechanical interests.

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