The impact of developmental instability and rate of maturation on neuropsychological measures:

A comparison of adults with and without adolescent idiopathic scoliosis

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Abstract

This study examined the impact of developmental instability and age of maturation on language lateralisation and cognitive ability in participants with adolescent idiopathic scoliosis (AIS) and controls.

Two studies have found evidence of anomalous language lateralisation in women with AIS, one finding an increase in lateralisation and the other a decrease. This study attempted to clarify these disparate findings, examine the theoretical basis for such results and the impact of relevant variables upon cognitive ability.

There are several possible reasons why one might anticipate such differences in lateralisation in people with AIS. It has been suggested that an increase in language lateralisation might occur because of increases in directional asymmetry in AIS, research having demonstrated increases of both directional and fluctuating asymmetry in AIS. Increased fluctuating asymmetry in the general population has in itself been linked to decreased intelligence and anomalous lateralisation of language. Anomalous lateralisation of language has also been associated with anomalous age of maturation and delayed or premature maturation has in turn been associated with AIS.

The participants were 74 adult women, half with AIS and half without the condition. Developmental instability was assessed using palmar interdigital ridge counts, age of maturation was obtained through self report of age of menarche, language lateralisation was assessed using the Fused Word Dichotic Task and cognitive abilities were assessed with the Wechsler Abbreviated Scale of Intelligence.

Results suggested few differences between people with scoliosis and controls; the only differences being increased directional asymmetry on the interdigital area a_b, increased total ridge count (a possible indicator of delayed in utero maturation) and increased scores on WASI performance tasks relative to verbal ones.

Results for the group as a whole suggested that fluctuating asymmetry was associated with increased developmental instability and that later age of maturation was associated with increased performance skills.

These findings are considered in the light of the current literature and the implications for clinical practice are discussed.

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1 Introduction

1.1 Overview

This study examines the relationship between functional cerebral asymmetry in the form of language lateralisation, physical asymmetry, age of maturation and neuropsychological measures of functional lateralisation and ability. These relationship between these variables is compared between people with adolescent idiopathic scoliosis (AIS), a spinal curvature of unclear origin and with people without the condition. Although the study focuses on people with adolescent idiopathic scoliosis, the relationship between these variables in people without AIS is also intrinsically of interest.

Whilst it may seem rather counterintuitive to investigate functional cerebral asymmetry in an apparently purely physically asymmetric condition such as AIS, there are strong theoretical reasons for anticipating differences in degree of lateralisation. There is also empirical evidence to suggest that such differences in lateralisation exist, although the two studies in the literature (Enslein & Chan, 1987; Goldberg, Dowling, Fogarty & Moore, 1995a) which have examined language lateralisation in AIS have found differences in opposite directions (e.g. both lesser and greater lateralisation of language). The current study replicates these previous experiments by using a dichotic listening task to assess lateralisation of language.

Previous research has found evidence of increased general asymmetry in AIS using palm prints (Goldberg , Dowling, Fogarty & Moore, 1995b). Unlike previous studies, this study uses the same measures of language lateralisation and asymmetry in the same cohort of participants to establish whether there is an association between physical asymmetry and functional asymmetry. This study also looks at the impact of age of maturation on verbal and non verbal ability.

Although this study focuses on differences between people with adolescent idiopathic scoliosis and controls, the relationships between the variables assessed should also apply to the general population. There are only a limited number of studies that have examined the neuropsychological impact of the variables in question so this study aims to add to the limited literature.

1.2 Scoliosis

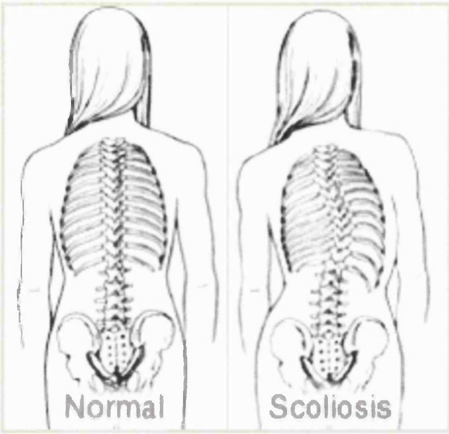


Figure 1-1 Diagram of normal spine compared to scoliotic spine

Scoliosis can be defined as a spinal curvature where the spine deviates laterally from the vertical position by more than 10 degrees (e.g. Koukourakis, Giaourakis, Kouvidis, Kivernitakis, Blazos, & Koukourakis, 1997) (see Figure 1). The degree of curvature is usually assessed by measuring the angle of interception between lines drawn parallel to the articular surface of the highest and lowest vertebrae involved in the curve (Strasburger & Brown, 1996). This angle is known as the "Cobb angle" and is the mostly widely used method of measurement. The spinal curvature may produce significant physical deformity, including scapular and rib prominence, uneven shoulders and an asymmetric waistline (e.g. Koch, Buchanan, Birch, Morton, Gatchel, & Browne, 2001).

Scoliosis frequently manifests as an "s" shaped curvature, with one major curve and a second, compensatory, minor curve, although single curvatures can also occur. Scoliosis is categorised as a "right" or "left" sided curve, depending on the side of the largest curvature. It is also sub-divided into "lumbar" and "thoracic" curves, depending on whether the curvature is in the lower or upper region of the spine (Dubousset, 1999). By far the most common configuration of curvature is the "right thoracic" pattern accounting for up to 98% of idiopathic curvatures (McCarver, Levine & Velaskis, 1971).

Scoliosis is associated with a number of medical conditions such as Marfan's syndrome (Pozdnikin, Ovechkina, & Ryzhakov, 1990), Rett's syndrome (Bassett & Tolo, 1990) and cerebral palsy (Saito, Ebara, Ohotsuka, Kumeta, & Takaoka, 1998). It can also be classified, as mentioned above, as "idiopathic", where the cause is unclear as no pathologic cause (i.e. paralysis, congenital malformation, or metabolic disease) can be determined. (e.g. Skaggs & Bassett, 1996; Dubousset, 1999).

Idiopathic scoliosis may be further categorised as congenital, infantile, juvenile, or adolescent, depending on the age of onset. Idiopathic adolescent scoliosis is the most common form with mass screening studies indicating a prevalence rate of 2-3% for curves over 10 degrees, with a decreased prevalence of 0.3-0.5% for curves over 20 degrees (Lonstein, 1988). Overall, there is a female to male ratio for adolescent idiopathic scoliosis (AIS) of 3.6:1, rising to 10:1 for curves over thirty degrees (e.g. Weinstein, 1999). This study focuses on adolescent idiopathic, since it is not only the most common, but it has also been associated with specific differences in lateralisation of language (Enslein & Chan,1987; Goldberg, Dowling, Fogarty, & Moore, 1995a).

1.2.1 Adolescent idiopathic scoliosis

Many studies of scoliosis appear to subsume adolescent idiopathic scoliosis under the general title of idiopathic scoliosis. This literature review will necessarily include such studies, with the caveat that whilst the majority of the participants with idiopathic scoliosis will generally have scolioses with an adolescent onset, participants with congenital, infantile or juvenile scolioses may also be included.

During growth, idiopathic scoliosis is generally a progressive condition (e.g. Duval & Lamireau, 1985) with the greatest increase in curvature usually associated with earlier onset of the condition (Lonstein, 1999). There appears to be some uncertainty in the medical profession as to whether the spinal curvature progresses beyond adulthood. Although many people with adolescent idiopathic scoliosis are told that their curvature will not progress once they reach age eighteen (Montgomery, Willner, & Appelgren, 1990), the literature suggests that curves with Cobb angles of over 35 will generally progress by one degree a year if left untreated (e.g. Bjerkreim & Hassan, 1982).

1.2.1.1 Genetic susceptibility to scoliosis

Another area of apparent uncertainty is the genetic basis of adolescent idiopathic scoliosis. It seems clear that at least some people with scoliosis have a family history of the condition. Concordance rates in monozygotic and dizygotic twins are 92% and 63%, respectively (Inoue et al., 1998) and there are currently a number of research programs examining the role of genetic factors in scoliosis (e.g. Miller, 1999). There is some evidence from these research programs that a genetic susceptibility to idiopathic scoliosis may also extend to congenital scoliosis.(Alman & Cole, 2002).

Unfortunately, estimates of the incidence of familial scoliosis vary widely, from 5% of cases in Ireland to 25% of cases in America (Goldberg, 2001, internet communication). Nancy Miller, a leading researcher in the field, believes that there are no official data available (Miller, internet communication). In fact there is one, small scale Spanish study, which found that 25% of 100 schoolchildren with idiopathic scoliosis had one or more affected individuals in their family (Martin, Rodriguez, Eguren-Hernandez, Diaz, de Leon, & Pedrosa-Guerra, 1997).

Miller suggested that the dearth of reliable surveys of incidence may reflect the fact that some relatives of affected individual may have scoliosis, but are unaware of it. In support of this hypothesis, she cited a recent survey she conducted with over 1200 individuals in families with scoliosis where 18% of relatives identified as having scoliosis did not know that they had the condition.

1.3 Treatment

Current treatments for adolescent idiopathic scoliosis include bracing and spinal fusion (e.g. Cassella & Hall, 1991). Past treatments have included physiotherapy, heat lamps, cotrel traction, electrical stimulation and hot spas (e.g. Avalle, Duelund, & Eder, 1981), but there is little evidence for the efficacy of such approaches (e.g. O'Donnell, Bunnell, Betz, Bowen, & Tipping, 1988). Treatment choice is determined by the patient's physical maturity, curve magnitude and location and potential for progression, with thoracic curves being at greatest risk of increased curvature (Scoliosis Research Society, 2000).

1.3.1 Bracing

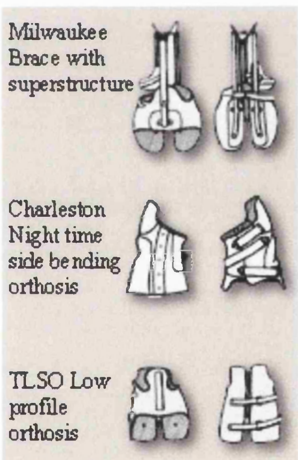


Figure 1-2 Braces used in adolescent idiopathic scoliosis

Braces are plastic and metal corset like structures that are generally used with adolescents with curve magnitudes of between 25 and 40 degrees who are skeletally immature and have significant growth remaining. The main goal of bracing is to arrest curve progression, with any improvement in curvature being seen as a bonus. Several types of brace exist; the more modern Boston brace and the nighttime Charleston brace, which are less obtrusive and the older Milwaukee type with chin rest which is very conspicuous (See Figure 1-2). The braces are usually made to fit the individual and as they grow, regular brace check ups are necessary, usually about once every three months.

Braces are generally supposed to be worn for twenty three hours a day. However, braces are often uncomfortable and unsightly and compliance is therefore frequently low (Blackman, 2002). One study reported that on average patients only wore their braces 65% of the prescribed time. (DiRaimondo & Green, 1988). Unfortunately, the efficacy of this mode of treatment is generally correlated with the length of time that the brace is worn per day (Bowen, Keeler, & Pelegie, 2001). It seems that if the brace is worn as prescribed, braces are an effective treatment for many adolescents with scoliosis (Howard, Wright, & Hedden, 1998).

1.3.2 Spinal Fusion

Surgical spinal fusion is generally only used with patients with curvatures over 40 degrees. In fusion, the individual vertebrae are fused together in as straight a position

Figure 1-3 Instrumentation used for spinal fusion

as possible, so that the curve is decreased by about 50% on average and further progression is avoided (Cochran & Nachemson, 1985). This approach can be used with both adolescents and adults.

The surgical process involves the straightening of the spine and attachment of metal rods (See Figure 1-3) in order to hold the spine in its new position. The spinal fusion itself may be effected by abrasion of the vertebrae so that small particles of bone are produced which over the course of about a year become solid and thus fuse the spine in a straight position (Blackman, 2002).

This is clearly major surgery and most operations take five to six hours (Penn State Orthopaedics, 2002). Currently, in adolescents this procedure necessitates two or three weeks off school (e.g. Vanderbilt, 2002; Iscoliosis, website). In the past, however, after spinal fusion patients were confined to bed for several weeks and then wore a plaster cast for up to ten months (Fonda, 2002).

1.4 Impact of scoliosis

The consequences of adolescent idiopathic scoliosis may vary considerably, depending on the degree and stability of the curvature (e.g. Dickson, Mirkovic, Noble, Nalty, & Erwin, 1995), age (Drummond, Fowles, Ecuyer, Roy & Kerner, 1976) and the type and success of treatment (Noonan, Dolan, Jacobson, & Weinstein, 1997); (Edgar & Mehta, 1988). The type of treatment is also important in as much as the treatments themselves have an impact on the patient, both physically and psychologically.

1.4.1 Physical impact of scoliosis

1.4.1.1 Effect of treatment

1.4.1.1.1 Bracing

Although it is a relatively noninvasive approach compared to surgery, bracing is not without its side effects. The immediate physical side effects include discomfort, a negative impact on renal function, (Berg & Aaro, 1983) and a reduction in lung capacity (Katsaris, Loukos, Valavanis, Vassiliou, & Behrakis, 1999). Long term physical consequences include reduced sagittal diameter and therefore possible effects on pulmonary function (Willers, Normelli, Aaro, Svensson, & Hedlund, 1993) and changes in dentofacial morphology in people who had previously worn Milwaukee braces (Lennartsson & Friede, 1981).

1.4.1.1.2 Spinal Fusion

Reported long term rates of lower back pain after spinal fusion vary widely from 7% to 66% (e.g. Padua, Padua, Aulisa et al., 2001). Furthermore, there are sometimes immediate post operative complications such as infection and longer term issues such as rod breakage (e.g. Dickson et al, 1995). That said, Dickson et al. (1995) found that in adult patients, those treated with spinal fusion were more similar to people without scoliosis in terms of function, appearance and symptoms, than to the non-treated group with scoliosis.

1.4.1.2 Effect of no treatment

The potential physical consequences of untreated idiopathic scoliosis in middle age include pain, cosmetic deformity, reduced heart and lung function and disability (e.g. Dickson et al., 1995)

1.4.2 Psychosocial impact of scoliosis

There seems to have been relatively little research into the psychological effects of scoliosis and the conclusions of these studies seem to vary significantly. A number of studies have suggested that women with scoliosis have lower rates of marriage and higher incidence of disability, unemployment and low self esteem (e.g. Nilsonne & Lundgren, 1968). However, a recent review of the psychosocial impact of scoliosis (U.S. Government, 2001) suggested that these studies were poorly conducted and that many of the participants had spinal conditions other than adolescent idiopathic scoliosis. There is evidence to suggest that during adolescence scoliosis is a risk factor for suicidal thought, increased use of alcohol and, rather understandably, worries about body development (Payne et al., 1998). However, the consensus of opinion in the limited literature that exists seems to suggest that these effects rarely persist into adulthood.

1.4.3 Neuropsychological impact of scoliosis

Most of the psychological literature has understandably focussed on the psychological impact of AIS. The neuropsychological aspects of AIS have remained relatively unexamined, save for two studies in the orthopaedic literature (Enslein & Chan, 1987; Goldberg et al.,1995a). In order to understand why there might be any role for a neuropsychological perspective on AIS, it is necessary to review the literature concerning the putative aetiologies of AIS.

1.5 Aetiologies of Adolescent Idiopathic Scoliosis

Despite the nomenclature of "idiopathic", a number of possible aetiologies have been suggested for AIS, and indeed, it has been said that the aetiology of AIS may in fact be "a complex, multifactorial jigsaw puzzle into which a multitude of pieces have to yet to be fitted" (Nachemson, 1984, p 143). A recent review of the literature (Miller, 1999) concluded that whilst a number of causes had been investigated, implicating connective tissue, neuromotor, hormonal (e.g. melatonin and growth hormone) and biomechanical abnormalities, there was currently no clear evidence to support any one area as the cause of scoliosis. The author also noted that one of the major difficulties encountered in this field was the issue of whether an observed abnormality was a primary cause or a secondary function of the scoliosis. This point is ably illustrated by research findings concerning vertebral asymmetry.

1.5.1 Vertebral Asymmetry

Unsurprisingly, given the nature of the deformity, the structure of the vertebrae in scoliotic individuals has been a focus of research since the 19th Century (e.g. Wever et al., 1999). It seems that a distinct vertebral asymmetry is evident at the apical region of thoracic curves, with significantly thinner pedicles on the concave side of the curve, than on the convex side (e.g. Liljenqvist, et al., 2002). This abnormal asymmetry has been thought to be caused by unusual loading from factors such as soft tissue posterior tethering (e.g. Enneking & Harrington, 1969). However, biomechanical modeling by Stokes, Gardner and Morse (1991) suggested that the force required to produce even a minor scoliosis by this means was so great that there did not appear to be any anatomic structures capable of producing such forces. They therefore concluded that the observed vertebral asymmetry was more likely to be the primary cause of the scoliosis than a secondary effect. However, there is still the question as to the cause of this asymmetry and any coherent account of the aetiology of the spinal asymmetry must also account for the fact that people with AIS also demonstrate increased asymmetry and abnormalities in other areas.

1.5.2 Neural Abnormalities and Asymmetry

Notably, a variety of neural asymmetries and abnormalities have been identified and again, it is hard to discount these as secondary consequences of the scoliosis itself. In his review of the literature, Edgar (1998) identified three main categories of neural mechanisms that had been implicated in the aetiology of adolescent idiopathic scoliosis, namely neurological dysfunction, abnormal neuro-hormones and abnormal neuroanatomy. Edgar concluded that there was evidence to suggest asymmetrical maturation and development of higher cortical control of equilibrium and that further work in this area was needed.

1.5.3 Non-Spinal Physical Asymmetries

Further support for the idea that non-spinal asymmetry may be a key factor in scoliosis comes from studies which suggest that asymmetry seen in scoliosis does not appear to be limited to the spine, or indeed other physical aspects such as leg length which could be caused by the curvature. For example, Yarom et al. (1982) documented asymmetrical hypotrophy of the deltoid arm muscles on the concave side of the curve in people with scoliosis. Other asymmetries have been noted in upper limb length, breast size, skull shape, and dentition (Burwell et al., 1977; Normelli et al., 1986; Goldberg & Dowling, 1991; Pecina et al., 1991).

1.5.4 Developmental Instability as an Aetiology of Adolescent Idiopathic Scoliosis

It has been suggested by several researchers (Goldberg, Dowling, et al. 1995b; Dangerfield, Scutt, Ashton, & Dorgan, 1997) that the observation of greater levels of general physical asymmetry in AIS can be understood in terms of "developmental instability". Developmental instability is a complex subject and the area will therefore be reviewed before discussing its role in adolescent idiopathic scoliosis

1.6 Developmental Instability

Developmental instability has been defined as the "imprecise expression of the genetic plan for development due to several well known genetic and environmental effects" (Yeo et al., 2000, p. 143). As implied in the previous quotation, it seems that some "genotypes are intrinsically more resistant to such destabilization than others." (Goldberg et al., 1997, p. 2229) and it is not surprising therefore to find that developmental instability appears to have a heritable component (Møller & Thornhill, 1997).

There are several different ways to assess developmental instability within a population such as identifying the frequency of phenodeviants, or congenital abnormalities within a population (Rasmuson, 1960). However, the most widely used approach is the measurement of deviation from normal bilateral symmetry in an organism. The advantages of this approach are twofold. Firstly, asymmetry occurs relatively frequently within a population, compared to congenital abnormalities, so this method can be used with smaller sample sizes. Secondly, the measurement of left and right sided aspects of a particular trait within an individual ensures that the contribution of environmental and genetic factors to asymmetry are held constant (Møller & Swaddle, 1997).

This approach is premised on the fact that organisms generally have a certain genetically pre-programmed left-right physical symmetry (with important exceptions such as the heart) (Van Valen, 1962). The development of symmetry within an organism can be affected by environmental stressors during the developmental period and thus the ability of the organism to develop symmetrically is a measure of its ability to resist the impact of such stressors.

Although increased asymmetry generally implies developmental instability, out of the three types of deviation from symmetry that can occur, only one, fluctuating asymmetry, is regarded as a clear measure of developmental asymmetry. The other two, antisymmetry and directional asymmetry do not necessarily represent a departure from normal development and therefore do not necessarily imply developmental instability (Møller et al., 1997).

1.6.1 Antisymmetry

"Antisymmetry" simply refers to the situation where asymmetry in an organism is normal, but the degree of asymmetry and the side on which it occurs cannot be predicted (e.g. Dangerfield, Scutt, Ashton, Manning & Dorgan, 1997). Fiddler crabs offer a very good example of antisymmetry, in that one of male's claws is always significantly larger than the other, but it is equally likely to be the left or the right claw (Neville, 1976). A frequency histogram of signed asymmetry (e.g. right minus left) where antisymmetry is present will demonstrate a bimodal distribution (See Figure 1-4).

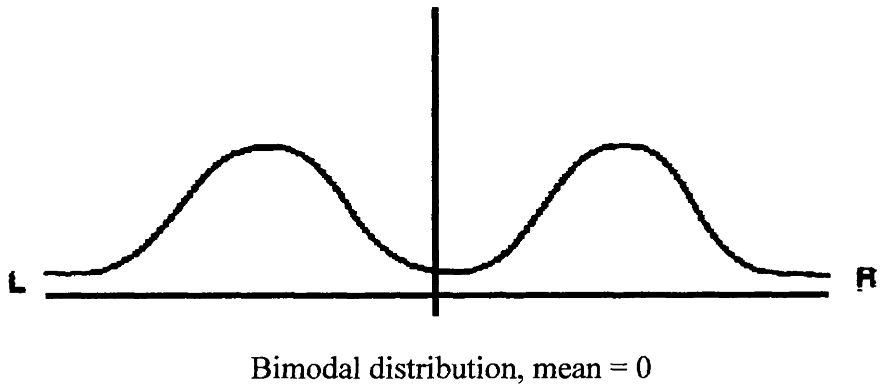
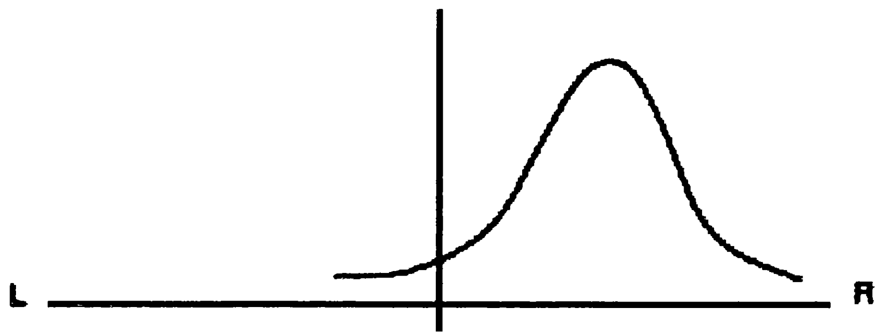


Figure 1-4 – Frequency histogram demonstrating antisymmetry

1.6.2 Directional Asymmetry

In "directional asymmetry" (Ludwig, 1932) there is normally greater development of a given trait on one side of the plane of symmetry relative to the other, so that one particular side is predictably bigger or longer, for example, than the other and there are therefore differences in the mean values for bilateral traits (Van Valen, 1962). In this instance, a frequency histogram of signed asymmetry (e.g. right minus left) will therefore demonstrate a large skew to either the right or the left, depending on the direction of the asymmetry (See Figure 1-5).



Normal distribution, mean < > 0

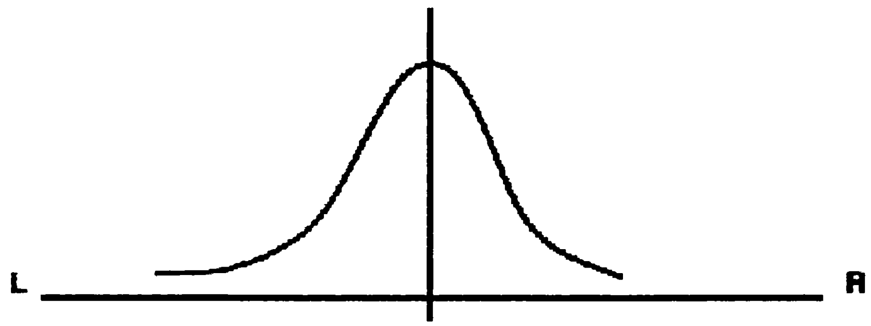
Figure 1-5 - Frequency histogram demonstrating directional asymmetry

Møller and Swaddle (1997) cite mammalian arterial arches as a good example of directional asymmetry. The systemic arch is normally on the left, although very occasionally, it may be on the right. One might also consider handedness in humans to be an example of directional asymmetry, in that the majority of humans are right hand dominant, although, a minority of the population exhibit reversed directional asymmetry by being left handed. In the case of handedness, and indeed directional asymmetry in general, the heritability of the direction of asymmetry suggests that directional asymmetry clearly has a genetic component (e.g. McManus, 1991).

1.6.3 Fluctuating Asymmetry

"Fluctuating asymmetry" is the most commonly used measure of developmental instability (Palmer & Strobeck, 1986) because, as previously noted, it represents a clear deviation from normal, bilaterally symmetrical development. Organisms with a high level of fluctuating asymmetry will have deviations from symmetry throughout their body, presumably because they possess insufficient developmental stability to develop symmetrically under environmental stress.

The deviation in symmetry has a random distribution so that the increase in size or length etc. is randomly distributed on the left and right sides of the body. Signed differences between left and right therefore have a mean value of zero, but the



Normal distribution, mean = 0

Figure 1-6 - Frequency histogram demonstrating fluctuating asymmetry

variance is significantly different from that of a symmetrical organism (e.g. Van Valen, 1962). In contrast to directional asymmetry, a frequency histogram of signed differences in a trait exhibiting fluctuating asymmetry will be normally distributed around a mean of zero (See Figure 1-6).

1.6.4 Measurement of asymmetry

1.6.4.1 Anthropometry

Anthropometry is simply the measurement of various traits, often using callipers to determine size and therefore in this case asymmetry (Burwell & Dangerfield, 1992).

1.6.4.2 Dermatoglyphics

"Dermatoglyphics" literally means "skin carvings" (Cummins & Midlo, 1961), an appropriate description for the ridges that are found not only on the fingers, but also on the surface of the palms. These ridges have been described as "'fossils' of late first and second trimester foetal development (Fearon, Lane, Airie, et al., 2001, p. 151) as the epidermal ridges form between the 11th and 24th week of development and remain unchanged thereafter (e.g. Green, Bracha, Satz, & Christenson, 1994). Any in utero disturbances that occur during this period such as maternal rubella may therefore result in abnormal dermatoglyphic patterns, particularly reduced ridge counts. (Alter & Schulenberg, 1966). Similarly, any innate bodywide tendency towards either fluctuating or directional asymmetry will also be reflected in the asymmetry in the number of ridges on each palm and set of finger prints of individuals within a given population (e.g. Naugler & Ludman, 1996). Notably, the skin and the brain both develop from the same ectoderm and it has been argued that dermatoglyphic abnormalities may also therefore reflect disturbances in brain development (e.g. van Oel, Baare, Hulshoff Pol et al., 2001).

1.6.4.2.1 Interdigital ridge counts

The measure of dermatoglyphic asymmetry that has been most frequently used in scoliosis is that of palmar asymmetry. (e.g. Goldberg et al., 1995b). With this method, ridge counts are performed between the interdigital tri-radii, a,b,c and d (See Figure 1-7). As can be seen from Figure 1-7 (next page), the tri-radii are the triangular like formations usually found around the base of each finger, where the ridges converge from three directions. Counting between them gives measures for three pairs of points; a – b, b – c, and c – d. Although the hands "mirror" each other in a roughly symmetrical manner (Cummins & Midlo, 1961)), these measures are thought to exhibit rightward directional asymmetry (Schaumann & Alter, 1976), in that the total number of epidermal ridges is generally greater on the right hand than on the left in 80% of people (Holt, 1968).

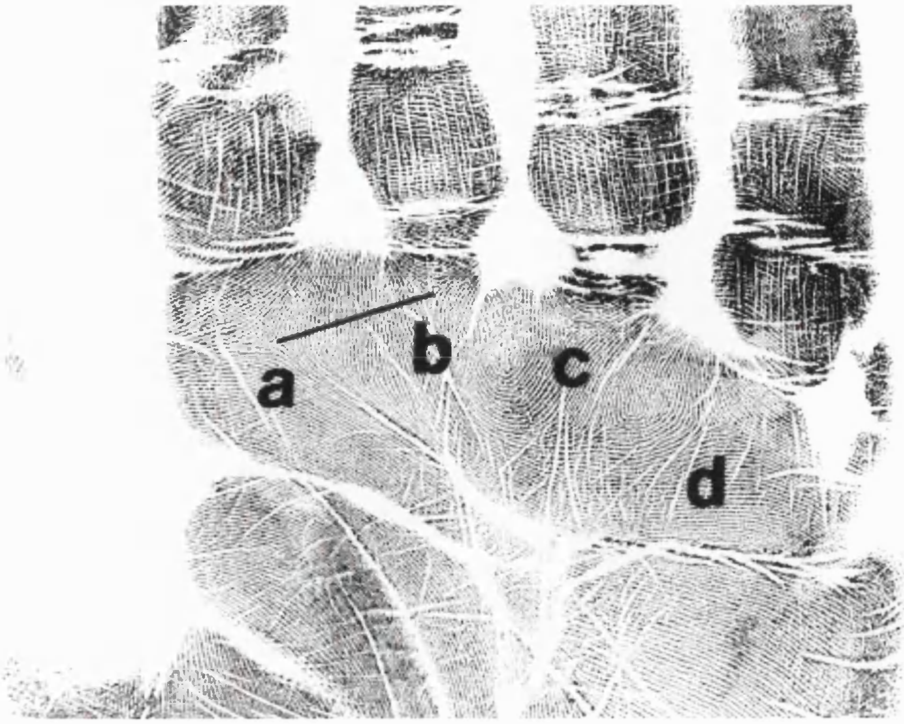


Figure 1-7 Palm print showing tri-radii a,b,c, and d

1.6.4.2.2 A-b ridge counts

Although there are therefore three measures possible, it seems that the a -b interdigital ridge count (See Figure 1-7) may be a particularly sensitive measure of developmental instability (Bogle, Reed, & Rose, 1994), in that it is more affected by environmental factors and less genetically determined than other dermatoglyphic indices (Holt, 1968). It has certainly been used as the sole measure in a number of studies. (e.g. Bogle et al., 1994).

It has been suggested that the apparent greater sensitivity of the a-b count may reflect the fact that the a-b area develops earlier and over a longer period of time in utero than either the fingers or the other interdigital areas and is therefore potentially exposed to a greater number of environmental stressors (Rose, Reed, & Bogle, 1987).

However, there may be a somewhat more prosaic explanation to the frequent usage of a-b counts alone. Jantz (internet communication) notes that researchers often restrict their measures to a-b interdigital counts alone simply because a small number of the population have missing "c" tri-radii and these participants would therefore have to be excluded from the study as they would have neither b-c or c-d counts. That said, Jantz' own study of over 2000 Germans (50% male; 50% female) (Jantz & Brehme, 1993) found that fluctuating asymmetry was most evident on palmar area c-d, then a-b and finally b-c, so the hypothesis that a-b is particularly sensitive to environmental stressors is not without support.

1.6.4.2.3 Factors affecting dermatoglyphic profiles

Dermatoglyphic profiles are not only affected by environmental stressors, but also gender. For example, males tend to have a greater total ridge count than females (Green et al., 1994). Similarly, it has been claimed that, although a degree of rightward asymmetry is the norm (Holt, 1968), the converse minority configuration, leftward directional asymmetry, is more common in females than males e.g. (Green et al., 1994). The finding of general rightward asymmetry may support the idea that the number of dermal ridges on the hands reflect the rate of in utero fetal growth, given that the right side of the body generally demonstrates faster cell division in the early stages of foetal development (Mittwoch, 1975).

However, once again the study by Jantz and Brehme (1993) found results that somewhat belie these generalisations. They examined all three palmar areas for directional symmetry and found that in general, b-c and c-d did indeed exhibit rightward asymmetry, but counts on a-b generally demonstrated leftward asymmetry. That said, they did note that women had larger left values than males for all three counts. A smaller study, with 222 participants, 99 female and 123 male found no evidence of differences in directional asymmetry between males and females, as measured by finger ridge count (Green & Young, 2000).

One other factor that has been associated with particular dermatoglyphic profiles is ethnicity. (e.g. Malhotra, Reddy, & Bhanu, 1995). Surprisingly, perhaps, handedness does not appear to be correlated with direction of ridge asymmetry, at least in heterosexual males and females (Kimura & Carson, 1995).

1.6.5 Heritability of Developmental Instability

It is generally accepted that certain genotypes predispose to developmental instability (e.g. Szappanos et al., 1997). For example, evidence suggests that there is an increased incidence of minor physical anomalies, a marker of developmental instability, in people with functional psychoses, compared to controls, leading to the speculation that there may be an overlap between the genes that predispose to psychiatric illness and those that predispose to developmental instability (McGrath, van Os, Hoyos, Harvey & Murray, 1995),. Subsequent research has supported the idea of heritable developmental instability by demonstrating that the first degree relatives of people with schizophrenia, as well as the patients themselves, had higher levels of developmental instability. (Arboleda, Ramcharan, Hreczko, & Fick, 1998).

It has been suggested that particular genotypes may predispose towards not only general developmental instability and fluctuating asymmetry, but also directional asymmetry (Boklage, 1985).

1.6.6 Implications of Increased Asymmetry

1.6.6.1 Implications of increased fluctuating asymmetry

One notable implication of increased fluctuating asymmetry may be its association with decreased general cognitive abilities (Furlow et al., 1997, Thoma, 2000). For example, Furlow et al. (1997) examined the relationship between anthopometric measures of fluctuating asymmetry and performance on Cattell's Culture Free Intelligence Test and found a significantly negative correlation of –0.244. They speculated that developmental instability might impinge upon ability in two possible ways. Firstly, they suggested that high levels of external fluctuating asymmetry may correlate with "compromised neurological structural integrity" (Furlow et al., 1997, p.

827) because of developmental stress during the early development of both brain and body. Secondly, they proposed that developmental instability might act on both the neuronal and the structural level to cause "suboptimally structured neurological phenotypes" (p. 827) that would result in increased processing error and decreased speed of processing

It is not surprising therefore to find that high levels of fluctuating asymmetry in children are also correlated with relatively poor working memory and poor executive function. (Yeo, Hill, Campbell, Vigil, & Brooks, 2000). Increased fluctuating asymmetry has also been associated with increased incidence of conditions such as Down's syndrome (Bell, Townsend, Wilson, Kieser, & Hughes, 2001) and schizophrenia (Fananas, van Os, Hoyos, McGrath, Mellor, & Murray, 1996). In people with schizophrenia, increased fluctuating asymmetry is even associated with increased severity of the condition (Markow, 1988).

In contrast, greater symmetry has been associated with better athletic ability (Manning & Pickup, 1998), sexual desirability (Gangestad, Bennett, & Thornhill, 2001) and greater fecundity (Møller, Soller, & Thornhill, 1995). These observations may suggest that fluctuating asymmetry serves as an important marker of genotypic fitness in humans (Wilson & Manning, 1996).

1.6.6.2 Implications of increased directional asymmetry

Although directional asymmetry has been regarded as adaptive asymmetry and not a deviation from the norm, it is arguable that significant differences in directional asymmetry may still be notable. For example, handedness could be seen as directional asymmetry, but the existence of handedness in the direction contrary to that generally expected (i.e. left handedness) is still seen as interesting and worthy of study (e.g. McManus, 2001). Furthermore, it has been proposed that any significant deviation from the norm, be that symmetry or directional asymmetry, may be evidence of developmental instability (Graham, Freeman, & Emlen, 1993).

Graham et al. (1993) suggested that when subjected to a sufficient degree of stress, a developmentally unstable individual will lose symmetry randomly to the right or left (i.e. fluctuating asymmetry). However, they hypothesised that individuals could also possess a directional developmental gradient, which would predispose them to lose symmetry in a particular direction. Thus, it is arguable that anomalous directional asymmetry may reflect a tendency to lose symmetry under developmental stress, in a particular direction.

The key factor in assessing the significance of any observed asymmetry would therefore seem to be whether directional asymmetry in a particular trait is a normal attribute for that trait in the general population and, if present, what direction and degree of asymmetry is normally exhibited.

Increased, decreased, reversed or absent directional asymmetry in a trait that normally exhibits directional asymmetry may be significant. Similarly, the presence of directional asymmetry in a particular trait in a particular sub-population where the trait is normally bilaterally symmetrical in the general population may also be notable.

In contrast to fluctuating asymmetry, there is no evidence to suggest that anomalous directional asymmetry is associated with decreased cognitive ability. However, there is evidence to suggest that the directionality of asymmetry in dermatoglyphic patterns may be associated with particular profiles of cognitive ability (e.g. Kimura & Clarke, 2001).

1.6.6.2.1 Directional Asymmetry and Cognitive Profile

Much of the evidence concerning directional asymmetry and ability comes from studies of the relationship between gender and directional asymmetry As noted in Section 1.6.4.2.3, there is evidence that directional asymmetry may vary as a function of gender. Levy and Levy (1978) hypothesed that this may occur because androgens promote the development of the right side of the body They supported this hypothesis by demonstrating that the right foot was generally bigger than the left in men, whilst the left foot was generally bigger than the right in women. Similar asymmetry has been reported in gonadal size, with males having larger right testicles and females larger left ovaries (Mittwoch & Mahadevaiah, 1980).

Somewhat remarkably, the direction of testicle and breast asymmetry in men and women is associated with differences in cognitive profile (Kimura, 1994). Men with the typical rightward asymmetry scored relatively high on tasks which usually favour males and women with the typically female leftward asymmetry scored relatively high on tasks which generally favour females. However, the pattern of ability followed directional asymmetry, not gender, so that right ward women demonstrated the same pattern of performance as rightward males and leftward males were more similar to leftward females.

Kimura and Carson (1995) replicated these results categorising participants as showing rightward or leftward directional asymmetry on the basis of right-left total finger ridge counts, an absolute difference of 2 or more ridges being the criterion for asymmetry. They used the same tasks as Kimura (1994), most of which are not in widespread usage in clinical practice in the U.K. The "masculine" favouring tasks included three visuospatial tasks: Paperfolding, and Hidden Figures (from the Educational Testing Service, Ekstrom, French, Harman & Dermen, 1976) and a Mental Rotations Test (Vanderberg & Kuse, 1978). The final task was Mathematical Aptitude, again from the Educational Testing Service (ETS). The "feminine" favouring tasks included two perceptual speed tasks; Identical Pictures and Finding A's from the ETS. The third task was a test of ideational fluency, the "Things Red" category, once more from the ETS. Kimura and Carson also included a category of "neutral" tasks that had not previously been shown to favour males or females. These tasks included Advanced Vocabulary and Inferences from the ETS kit and an abbreviated 15 item version of Raven's Standard Progressive Matrices (Harshman, Hampson & Berenbaum, 1983).

As predicted, participants with leftward directional asymmetry were better at "feminine" tasks and participants with rightward asymmetry were better at "masculine" tasks. However, Kimura and Carson were surprised to discover that participants with rightward directional asymmetry were also better on the supposedly gender neutral tasks.

A number of subsequent studies have used this paradigm. Kimura and Clarke (2001) replicated the previous finding that participants with leftward asymmetry were better at female favouring tasks. However, they also found that that rightward asymmetry was also associated with better performance on a supposedly gender neutral reasoning task. They found no effect of directional asymmetry upon performance in supposedly "masculine" and therefore rightward favouring spatial tasks. They concluded that the mixed pattern of results concerning rightward asymmetry and cognitive profiles was consisted with the understanding of behavioural masculinisation as "complex and multifaceted, with different aspects hormonally influenced at different prenatal periods," (Kimura & Clarke, 2001, p. 585). They noted that the finding of consistently different (if not necessarily consistently similar) cognitive patterns associated with leftward and rightward directional asymmetry indicated "somewhat different brain organisation." (Kimura & Clarke, 2001, p. 585).

The precise nature of this different brain organisation and the mechanism by which is occurs remains unclear. One possibility is that leftward asymmetry might correlate with greater left hemisphere facilitation due to increased directional growth in both brain and body; alternatively, it has been suggested that leftward asymmetry might be associated with enhanced cerebral commissures, or connections between the two hemispheres of the brain (Saucier & Kimura, 1996).

These ideas were tested by Saucier and Kimura (1996), using a dichotic listening task (See Section 1.7.2.1.4 for description of similar tasks) and a tachistoscopic measure of interhemispheric transmission. Participants were again categorised as having leftward or rightward directional asymmetry on the basis of finger ridge counts. As in a previous study (Hall & Kimura, 1993) leftward participants demonstrated a reduced right ear advantage on the dichotic listening task, due to an increased incidence of the atypical left ear advantage in this group (See Section 1.7.2.1.4 for discussion of ear advantages). Saucier and Kimura also found that participants with leftward asymmetry had facilitated interhemispheric transmission relative to participants with rightward asymmetry. Although they surmised that this indicated greater commisural development, there was no clear indication of why this might be.

1.6.6.2.2 Directional Asymmetry as Evidence of Developmental Disturbance

As noted, directional asymmetry may reflect the combination of developmental stressors and a directional developmental gradient. There is evidence from research with people with schizophrenia that directional asymmetry, specifically a-b dermatoglyphic asymmetry, may be a marker for in utero developmental disruption.

One study (Davis & Bracha, 1996) compared a-b ridge counts between three groups of monozygotic twins: twin pairs who were either concordant or disconcordant for schizophrenia and normal twins. Where only one twin had a diagnosis of schizophrenia, they found a leftward asymmetry in the a-b ridge count (i.e. a reduced ridge count on the right, but not the left hand) in the affected twin. There were no such differences in either the twins concordant for schizophrenia or those where neither twin had the condition. Similarly, Fearon et al. (2001) also found increased a-b asymmetry in people with schizophrenia, relative to controls, although their findings indicated rightward asymmetry.

The increased or reversed directional asymmetry observed in these studies has been interpreted as indicative of in utero developmental disruption.

1.6.7 Developmental Instability and Adolescent Idiopathic Scoliosis

It is this "directional asymmetry" that Goldberg et al. (1995b, 1997) suggested was demonstrated in AIS. She hypothesised that the increased physical asymmetry found in scoliosis (See Section 1.5.3 above) may indicate that scoliosis is the manifestation of increased general asymmetry throughout the body caused by "directional developmental destabilisation under physiologic stress" (Goldberg et al., 1997, p. 2228). In support of this hypothesis, Goldberg et al. (1995b) found that whilst children with non-scoliotic trunk asymmetry demonstrated increased fluctuating asymmetry relative to controls, children with AIS also showed an increased left-right directional asymmetry on dermatoglyphic measures. Specifically, adolescents with scoliosis showed increased leftward asymmetry on the palmar areas a-b and b-c, relative to controls, and increased rightward asymmetry on c-d, relative to controls. In a later study, (Goldberg et al., 1997) they found non-significant increases in the same direction; the only significant directional asymmetry being leftward asymmetry of the atd angle.

Other researchers have also found evidence of increased directional asymmetry in the upper limbs of people with scoliosis (Burwell & Dangerfield, 1992; Burwell, Dangerfield, James, Johnson, Webb & Wilson, 1984; Dangerfield, 1994). It appears that the direction of this asymmetry generally correlates with the direction of the curve, which in turn is strongly associated with handedness (Goldberg & Dowling, 1990).

It seems that people with AIS also exhibit increased fluctuating asymmetry. Notably, it seems that there is a very strong positive correlation between the degree of fluctuating asymmetry and the severity of curvature (Dangerfield et al., 1997).

As Stokes (1997) commented, the idea that developmental instability is a major factor in AIS could represent a new paradigm within the scoliosis literature which could accommodate many diverse research findings. Indeed, it could account for the bodywide asymmetries noted previously as well as asymmetrical vertebrae and the asymmetrical neural development noted by Edgar (See Section 1.5).

1.6.7.1 Developmental instability, mother's age and adolescent idiopathic scoliosis

Developmental instability is associated with a number of factors including increased maternal age (e.g. Møller & Thornhill, 1997). It is notable that some studies have reported increased maternal age in mothers of children with scoliosis (e.g. Wynne-Davies, 1968) and a positive relationship between maternal age and degree of curvature in children with scoliosis (Henderson et al., 1990), mirroring the association between increased fluctuating asymmetry and severity of schizophrenia, reported in Section 1.6.6.1.

However, other studies have found no relationship between maternal age and scoliosis (Enslein & Chan, 1987). It may be that these, and other inconsistent findings in the literature, can be understood as reflecting the fact that whilst many of these factors may increase or impact upon developmental instability and thus the likelihood of scoliosis, none of them reliably account for a significant proportion of cases.

1.6.7.2 Developmental Instability, rate of maturation and adolescent idiopathic scoliosis

It is possible that the adolescent growth spurt may be the catalyst to the development of scoliosis in some children as early maturation has been seen as a stressor to organisms' developmental stability (e.g. Møller & Swaddle, 1997). There is evidence to suggest that the growth pattern in children with adolescent idiopathic scoliosis is indeed different from that of their non-scoliotic peers. Several studies have reported that children with scoliosis demonstrate an earlier growth spurt than children without scoliosis (e.g. Nordwall & Willner, 1975; Nissinen, Heliovaara, Seitsamo & Poussa, 1993). Indeed, an increased level of growth hormone in younger girls with scoliosis has also been identified as the possible cause of this earlier maturation (e.g. Hagglund et al., 1992; Skogland & Miller, 1980). These observations have been used to account for the excess of scoliosis in females, as females tend to mature earlier than males.

It is tempting to speculate on the possibility of an interaction between developmental instability and early maturation. This might suggest that a high degree of developmental instability coupled with the normal adolescent growth spurt may lead to scoliosis, whereas in individuals with less intrinsic developmental instability, it may take a greater stressor such as early maturation to induce scoliosis.

However, the picture is complicated by the fact that not all girls with scoliosis demonstrate earlier maturation; indeed some studies have found later maturation in women with scoliosis compared to controls, particularly in women with greater curvature (Drummond & Rogala, 1980). The picture regarding maturation is therefore unclear.

1.6.8 Implications of increased developmental instability in adolescent idiopathic scoliosis

Goldberg's findings are central to the current proposal, since as noted in Section 1.6.6.2, direction of dermatoglyphic asymmetry has been shown to be related to the direction of lateralisation of cognitive function and patterns of cognitive ability (Saucier & Kimura, 1996). Furthermore, developmental instability itself has also been linked to cerebral lateralisation (Yeo et al, 1997).

Like developmental instability, lateralisation is a topic in itself and the area will therefore be reviewed before examining it in connection with developmental instability and adolescent idiopathic scoliosis

1.7 Lateralisation

Lateralisation refers to the process whereby behavioural and functional processes are lateralised to one side (e.g. Reber, 1985). Behavioural lateralisations are physical preferences for a particular side of the body and include handedness, footedness and ear and eye preferences. Functional lateralisation is the term given to the association of different functions and processes with one or another side of the brain. The most well known example being the lateralisation of language to either the left or the right hemisphere of the brain. (e.g. McManus, 2001).

Lateralisation to a particular side in one domain (e.g. right handedness) is often associated with a particular lateralisation in other domains (e.g. left hemisphere language) (Knecht, Deppe, Draeger et al., 2000). The association between right handed dominance and left hemispheric dominance probably reflects the fact that the brain exerts contralateral control over the body (e.g. Reber, 1985). The relationship between lateralisations is far from simple however and individuals may demonstrate mixed lateralisation over several domains (eg. right handed, but left footed) (Porac & Coren, 1981).

Lateralisation has been found to affect a range of issues such as occupation (e.g. Govier & Boden, 1997), incidence of dyslexia (e.g. Bloch & Zaidel, 1996), schizophrenia (Saugstad, 1998) and autonomic nervous system functioning (Wittling, 1995).

1.7.1 Handedness

Handedness is the most familiar example of behavioural lateralisation. In general, about 92% of the population are right handed, preferring to use this hand for writing and other tasks requiring fine motor control (e.g. McManus, 1985). As noted above, hand preference is a behavioural lateralisation that has been associated with particular patterns of language lateralisation. The classic pattern of language lateralisation is that 95% of right handers have left hemisphere language lateralisation, whereas only 70% of left handers demonstrate this pattern - the remaining 30% of lefthanders being split equally between right hemisphere and bilateral representation of language (Rasmussen & Milner, 1977). However, handedness does not appear to necessarily correlate highly with other behaviour laterality measures such as ear or eye dominance (Papousek & Schulter, 1999).

1.7.2 Language lateralisation

The most salient example of functional lateralisation is that of language, which is typically predominantly processed by the left hemisphere, although the right hemisphere demonstrates some linguistic ability and is thought to be important for the processing of emotional tone (e.g. Ley & Bryden, 1982).

1.7.2.1 Measures of Language lateralisation

1.7.2.1.1 Wada Testing

Wada Testing is the "gold standard" of language lateralisation (Brockway, 2000) by which all other methods are measured. The method was discovered inadvertently by a young Japanese doctor, Dr. Wada (Wada & Rasmussen, 1960). He found that if he injected an anesthetic, sodium amytal, into the carotid artery supplying one side of the brain and thereby anaesthetized one hemisphere, patients sometimes demonstrated temporary aphasias and other language disorders. By systematically anaesthetizing first one hemisphere and then the other and observing the effects upon language, it was possible to determine which hemisphere played the greatest role in language processing.

This procedure has proved invaluable prior to major brain surgery, particularly surgery for epilepsy (Watson, Pusakulich, Ward, & Hermann, 1998). When contemplating excising large amounts of brain tissue in one hemisphere, surgeons need to know whether they will be significantly disrupting language processing. The determination of language lateralisation by Wada testing prior to surgery ensures that this consequence is avoided as much as possible.

1.7.2.1.2 Imaging and transcranial doppler assessment

Although the Wada is a very reliable test, it is also invasive and therefore not appropriate for use in healthy populations. Increasingly, non-invasive technologies have been used to determine the lateralisation of language. For example, functional magnetic resonance imaging (fMRI) can be used to assess blood oxygen levels during the performance of particular tasks, thus providing images of hemispheric activity (e.g. Rutten, 2002). Similarly, transcranial doppler (TCD) can be used to assess relative hemispheric blood flow during task performance and therefore the relative contribution of the two hemispheres to any given task (e.g. Stoll et al., 1999).There is also evidence to suggest high concordance with Wada testing for fMRI (Desmond, Sum, Wagner, & Demb, 1995) and TCD (Rihs et al. 1999).

Although these methods are valid and reliable, they are also expensive clinical resources and therefore difficult to obtain access to for research purposes.

1.7.2.1.3 Split visual field

One method of assessing language lateralisation that is non-invasive, cheap and even portable is the split visual field technique. In this approach, the individual being assessed is require to fixate at a central point on a screen. Words are then presented either side of the fixation point. The relative facility with which an individual reports words presented to each visual field, and therefore each hemisphere, is believed to reflect the extent to which language is processed in the relevant hemisphere.

Despite the practical advantages of this method, it has only moderate validity when compared to the Wada test (Channon, Schugens, Daum, & Polkey, 1990).

1.7.2.1.4 Dichotic listening

One approach to the assessment of language lateralisation that may be both practical and valid is dichotic listening. There are several forms of the dichotic task, but the basic premise is that two auditory stimuli are presented simultaneously, one to each ear (Kimura, 1961).

. The technique relies on the fact that, just as sensory input from each side of the body goes directly to one hemisphere of the brain, so there are auditory pathways from each ear to the opposite hemisphere (see Figure 1-8). As well as contralateral pathways, there are also ipsilateral pathways, but it has been argued that these are suppressed in favour of the contralateral pathways during the dichotic listening task (Kimura, 1961).

Once information has reached one hemisphere, it is able travel to the other hemisphere via the commisurretomies. However, because language is generally lateralised to only one hemisphere, auditory input to the ear contralateral to the side of language lateralisation will be processed somewhat faster than auditory input to the ipsilateral ear. This faster processing means that stimuli presented to the ear contralateral to the hemisphere dominant for language are more likely to be reported by the participant.

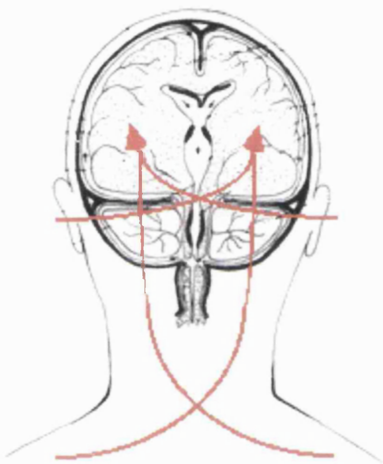


Figure 1-8 Cross lateral auditory and motor pathways

Most right handed individuals demonstrate a right ear advantage, which is therefore suggestive of left hemisphere lateralisation of language (Kimura, 1961).

It seems that dichotic listening tasks are generally quite effective at measuring lateralisation at the group level in this way. However, as with the visual split field paradigm, on an individual basis they may be less effective. Lee compared the results of dichotic listening tasks against Wada testing of in 106 individuals (Lee, 1995). He concluded that it dichotic listening performance could not be regarded as a valid predictor of language dominance.

However, there is one particular kind of dichotic listening task that appears to be a far better prediction of language dominance, the Fused Words Dichotic Test (FWDT) (Wexler and Halwes, 1983). In the FWDT as in other dichotic listening tasks, two words are presented simultaneously to both ears, one word per ear. However, in the FWDT, the words consist of rhyming words that have been carefully selected and manipulated so that the two words fuse into a single percept and the subjective experience is of hearing one word.

Again, the extent to which participants report hearing words presented in the right or left ear is believed to reflect the lateralisation of language.

Studies have been carried out comparing the results of the FWDT with the Wada. These studies suggest that this noninvasive test can predict language lateralisation with up to 100% accuracy in both individual adults (Zattore, 1989) and children (Fernandes & Smith, 2000). The FWDT has therefore been used as a non-invasive measure of language lateralisation in a number of research studies (e.g. Bruder, Rabinowicz, Towey, Brown, & Kaufmann, /6).(di Stefano, Salvadori, Fiaschi, & Viti, 1998)

1.7.2.2 Degrees of language lateralisation

Although there is a relationship between structural asymmetry and functional lateralisation (Foundas, Leonard, Gilmore, Fennell, & Heilman, 1994), Galaburda (1995) noted that the directionality of structural asymmetry does not always correlate highly with functional lateralisation and that the magnitude of the asymmetry may be a critical factor in the relationship between structure and function. He observed that a constant degree of asymmetry would be developmentally unlikely and that indeed in both humans and animals, individual anatomic asymmetry appears to vary along a continuum from near symmetry to extreme asymmetry (Galaburda, 1995). It is therefore not just the directionality of anatomical asymmetry in a given individual that is of interest, but also the degree of asymmetry. Similarly, the magnitude of functional lateralisation may be an important consideration. As Zangwill (1960, p27) noted, the lateralisation of language is "a graded characteristic, varying in scope and completeness from individual to individual." For example, when functional lateralisation of language has been assessed via hemispheric blood flow, it was found to occur along a bimodal *continuum* (Knecht et al., 2000).

1.7.3 The influence of age of maturation and anomalous asymmetry on lateralisation

When considering the effect of these factors, it is important to bear in mind the general development of the brain. The brain exhibits directional asymmetries in various structures such as the planum temporale (Geschwind & Levitsky, 1968) which are associated, to a greater, and sometimes to a lesser extent (Galaburda, 1995), with functional abilities (in this case language and handedness). There is evidence to suggest that the growth rate of the cerebral hemispheres varies differentially throughout the growth period. Initially, it seems that the right hemisphere exhibits faster growth than the left hemisphere (Geschwind & Galaburda, 1985), the left hemisphere then overtakes the right in terms of growth rate and finally the right hemisphere demonstrates faster growth as before. Changes to this pattern of growth can therefore produce unusual asymmetries and, arguably, differences in ability (Mittwoch, 1978). Early in utero factors that affect symmetry and initial brain development may be reflected in dermatoglyphics measures whilst maturation rate during puberty may provide an index of the speed of the final developmental process of the brain during adolescence.

1.7.3.1 The impact of rate of maturation on lateralisation

Saugstad (1989; 1998) suggested that the rate of maturation in adolescence may potentially have a fundamental impact on cognitive function and ultimately mental health, through its impact on the final stage in brain development, synaptic pruning.

Saugstad described this process as consisting of the "systematic elimination of redundancy of neuronal synapses (some 40%), perhaps to increase the efficiency of communication between the billions of neurons." (Saugstad, 1989, p. 161). This pruning leads to a decrease in excitatory synapses, although it does not apparently affect inhibitory connections.

Saugstad hypothesised that in extremis later maturation may lead to prolonged synaptic pruning which in turn may lead to a reduction in the number of excitatory synapses and an increased risk of schizophrenia. Conversely, he suggested that fast maturation might lead to increases in excitatory synapses and an increase in the incidence of manic depressive psychosis. He supported these assertions with a comprehensive review of the relevant literature. Neurophysiological support for his theory of maturation and synaptic pruning was provided by Kaiser and Gruzelier (1999). They used EEG measures and P3 latencies, an event related potential measure of speed of response to novelty to assess excitatory brain response to stimulation and found results in line with Saugstad's hypothesis.

Whether or not this postulated mechanism is correct, there is evidence to suggest that rate of maturation may indeed affect language lateralisation and performance on verbal and non-verbal tasks.

With regard to language lateralisation, Waber (1976) demonstrated that age of maturation (i.e. puberty) in adolescents was related to degree of language lateralisation, as measured by a dichotic listening task. She found that later maturers had larger ear advantages than earlier maturers, irrespective of whether lateralised to the left or right hemisphere.

Vrbancic (1989) found an association of age of maturation and direction of lateralisation. Her study found early maturers demonstrated stronger left ear advantages on a dichotic listening task and therefore presumably stronger rightward cerebral directional asymmetry for language.

There are mixed findings concerning the impact of maturation on left hemisphere and right hemisphere lateralisation and actual ability. Waber (1979) found that late-maturing children between ten and sixteen years of age of both sexes performed better than early maturers on tests of spatial ability, including WISC block design, although the groups did not differ on tests of verbal ability. It has been suggested that bilateral representation of language in left handers may lead to consequent "crowding" of spatial function and therefore poorer visuospatial skills (Levy, 1969). Conversely, one might explain better performance skills in a late maturing group by positing that if, as noted above, later maturation is associated with greater left hemisphere lateralisation of language, then visuo-spatial skills may have greater "space" to develop in the right hemisphere.

However, using a sample of 50 right handed adult females, Strauss and Kinsbourne (1981) found no evidence for a relationship between age of maturation as indicated by menarche and performance on visual and spatial tasks. They concluded that Waber's findings were a function of the fact that her participants were still developing.

Newcombe, Dubas and Baenninger (1989) reported that later age at menarche as assessed by self report from female undergraduates was associated with greater right hemisphere lateralisation for a spatial dot location task but not with higher spatial ability. Better spatial ability was actually correlated with stronger left hemisphere lateralisation for the dot location task and balanced lateralisation on a language task. These findings led Newcombe et al. to suggest that variability in findings regarding cognitive correlates of timing of puberty might be related to variability in strategies for approaching tasks.

One study has found a relationship between dermatoglyphic indices of maturation in utero and age of maturation at puberty, leading the authors to suggest that individuals "remain on the same tempo of development set down in prenatal life." (Meier et al. 1987, p. 357). This finding may suggest that the correlation between age of maturation at puberty and lateralisation might reflect the effects of prenatal speed of maturation as much as pubertal.

1.7.3.2 The impact of fluctuating and directional asymmetry on lateralisation

It has been suggested that developmental instability "overrides programmed laterality and handedness, in the same way that it perturbs the bilaterally symmetrical expression of morphological and metric traits." (Markow, 1992, p. 87).

As noted in Section 1.6.6.1, there is evidence to suggest that fluctuating asymmetry is associated with differences in functional lateralisation. Yeo et al. (1997) demonstrated that increased fluctuating asymmetry was associated with anomalous lateralisation on a composite measure of functional asymmetry that included the FWDT. One might interpret this study as demonstrating that the dermatoglyphic measures and the measures of lateralisation are both reflecting the impact of prenatal developmental stress. Prenatal stress in some way disrupts the normal development of the brain. This hypothesis might be supported by two other studies. One by Thoma (2002) found that fluctuating asymmetry correlated significantly with anomalous structural brain asymmetry and a previous study (Thoma et al., 1996) found that fluctuating asymmetry was correlated with greater atypicality of planum temporal asymmetry, which has been associated with language lateralisation.

The relationship between physical and functional asymmetry in the brain is still unclear (e.g Geschwind & Galaburda, 1985), so the impact of increased directional asymmetry is therefore unclear. However, imaging studies have suggested that leftward asymmetry of the planum temporale is associated with language lateralisation in the left hemisphere, whereas rightward asymmetry is associated with language in the right hemisphere (Foundas et al., 1994) Similarly, right handedness appears to be associated with significant leftward asymmetry of the motor hand area of the precentral gyrus, although in lefthanders there appears to be no directional asymmetry (Foundas et al, 1994). It seems that there are therefore some tentative grounds for suggesting a possible relationship between directional asymmetry and functional lateralisation.

1.7.4 Lateralisation and scoliosis

1.7.4.1 Hypothetical mechanisms of increased functional lateralisation in people with scoliosis

As noted, scoliosis may reflect an innate, possibly genetic, tendency towards developmental instability and asymmetry which might produce an increased asymmetry in lateralisation. One might also hypothesise that the particular pattern of growth associated with scoliosis could also lead to increased lateralisation. Saugstad (1998) suggested that early fast maturation was associated with right handedness, increased leftward asymmetry of the planum temporale, (which is associated with language processing), and a concomitant left hemisphere advantage. Thus one might anticipate that people with scoliosis might demonstrate such increased leftward asymmetry as a function of earlier growth.

However, as noted, Vrbranic (1989) demonstrated that early maturation was actually associated with decreased right ear advantages and increased left ear advantages, suggesting that early maturation produced a decreased left hemisphere advantage.

1.7.4.2 Studies of lateralisation in scoliosis

Lateralisation has been assessed in scoliosis both in terms of degree of lateralisation and direction of lateralisation. The interest in this area has largely focussed on the latter.

1.7.4.2.1 Behavioural Lateralisation

Given the predominance of right convex curvatures in scoliosis (e.g. Miles, 1944) , there has been some interest in the link between lateral preferences and direction of curvature. Sahlstrand (1980) analysed the lateral predominance of 51 patients with scoliosis as measured by hand, foot and eye preference and labyrinthine (vestibular) sensitivity. Whilst a significant difference was found between patients with right and left convex curves in terms of eye predominance and labyrinthine sensitivity and the direction of convexity was correlated with the predominant labyrinth for both groups, the direction of convexity was not correlated with the direction of lateral predominance. Sahlstrand therefore concluded that organisation of "motoric superiority for the extremities (was) not linked to the pathogenesis of adolescent idiopathic scoliosis." (p. 515).

In a similar vein, Goldberg and Dowling (1990) also correlated handedness with convexity of curve. However, they argued that the configuration of the whole spine should be considered when assessing convexity. Unlike previous research, curve patterns were assigned to right or left on the basis of the convexity of the low thoracic component only, regardless of primary curve. They found 82% concordance rates for curve convexity and handedness and concluded that this was evidence for an association between scoliosis and cortical functionGoldberg and Dowling (1991) found evidence to support the idea that people with AIS might demonstrate increased lateralisation for handedness and footedness. They examined hand or foot preference in children with AIS, children with non-scoliotic truncal asymmetry and controls with no asymmetry. They found that whilst there was no difference in hand or foot preference between these groups (ie. no consistent direction to their group directional asymmetry), there was a statistically significant tendency for children with any degree of asymmetry to show uniform lateralization in the sense of consistency of side preference. (ie. increased individual directional asymmetry).

1.7.4.2.2 Functional Lateralisation

Despite several lines of evidence supporting the possibility of anomalous lateralisation in scoliosis, there is little research on this topic. Indeed, there appear to be only two studies in the literature that specifically assess the lateralisation of language in people with scoliosis.

Following their conceptualisation of scoliosis as a manifestation of developmental instability and asymmetry, Goldberg et al. (1995a) hypothesised that any increase in asymmetry would not be limited to the motor cortex alone, but could extend to other functions such as language processing. In order to assess language lateralisation they utilised Wexler and Halwes' Fused Word Dichotic Task (Wexler & Halwes, 1983). This task was presented to a total of 31 adolescents with scoliosis (average age: 14.5, average angle of curve: 31) and 20 adolescents without scoliosis or any other visible deformity or spinal condition (average age: 14.2).

Goldberg et al. found that scoliotic participants demonstrated greater lateralisation for language than controls without scoliosis, the mean scores being 0.43 and 0.29, respectively, where a score of 0 represents symmetry. They did not assess the localisation of language (ie. left or right hemisphere), just the degree of lateralisation. However, only six participants demonstrated negative scores suggestive of right hemisphere lateralisation of language and these six people were equally distributed between the scoliotic and non-scoliotic group.

However, these findings appear to be completely contradicted by an earlier, somewhat atheoretical paper by Enslein and Chan (1987). Enslein and Chan's study was prompted by their anecdotal observation that their spinal fusion patients appeared to perform well at school in subjects such as language and solid geometry that they deemed to be associated with the right hemisphere and less well at subjects such as algebra and history that Enslein and Chan regarded as more under left hemisphere control. This observation led them to hypothesise that adolescent idiopathic scoliosis patients might be "more likely <u>not</u> to be left hemisphere dominant" (Enslein & Chan, 1987, p 979).

They examined this idea by presenting 21 AIS female scoliosis patients (average age 14.2, range 10 – 16) with a dichotic listening fused syllable task utilising 2 different nonsense syllables (e.g. ba/ga). Enslein and Chan did not have a control, non-scoliotic group, but compared performance on this task with 18 adolescents with progressive scoliosis (an minimum increase of 5 degrees over 3 months) and 13 adolescents with non-progressive scoliosis. They found that the former group evinced less left hemisphere lateralisation for language than the latter, the mean scores being 0 and 0.14, respectively, where a score of 0 again represents symmetry, 1 represents all the syllables reported coming from the right ear and –1 represents all the responses being heard in the left ear. They concluded that whilst the difference was statistically significant, the results should be viewed with caution since there were a relatively small number of participants.

The dichotic listening task formed only a part of what Enslein and Chan termed a "multiparameter pilot study of adolescent idiopathic scoliosis" (Enslein & Chan, 1987, p. 978).They concluded their paper by noting that they had also collected information on a number of variables including anthopometric measures, growth rates and scholastic performance, saying that the results would be reported in a subsequent paper. Unfortunately, it seems that these results were never published and are not available for study (Chan, internet communication).

The unavailability of the data regarding scholastic performance is particularly disappointing, since Herman, Mixon, Fisher, Maulucci, and Stuyck (1985) reported that a third of a sample of children with scoliosis demonstrated "academic malachievement", as identified by their school. Furthermore, this "malachievement" was strongly correlated with visuovestibular functioning and visuo-spatial deficits, leading Herman et al. to conclude that a higher level CNS disturbance might account for their findings.Herman et al. did not provide much information about the nature of this academic malachievement, but their findings regardingvisuo-spatial deficits do not seem to fit into Enslein and Chan's hypothesis of improved right hemisphere functioning. It would therefore have been interesting to have seen Enslein and Chan's data regarding school performance.

1.7.4.2.3 Accounting for the contradictory findings

The degree and localisation of lateralisation has potentially important implications and it would therefore be useful to be able to account for the difference in findings between these two studies. Goldberg did not cite Enslein and Chan's study because she did not find it in her literature search (Goldberg, internet communication), so it is not clear how she might have accounted for the different findings.

It is possible that differences in inclusion criteria may have affected results. Goldberg et al. (1995a) noted the handedness of participants, and only included patients with a minimum age of onset of scoliosis of ten. In contrast, Enslein and Chan did not report either of these variables. It is possible therefore that their participants were different in some fundamental way from those of Goldberg et al.

One small scale survey (n=42) has found a non-significant but notable increased incidence of left handedness (20%) in all forms of scoliosis with an onset prior to adolescence (Goldberg & Dowling, 1991) so the omission of both handedness and onset data may be particularly problematic. Left handedness is associated with reduced lateralisation of language, so if Enslein and Chan had selected a group with a significant number of earlier onset scolioses, one might anticipate their results.

Earlier onset scoliosis (before age 10) is also associated with a greater incidence (20%) of intraspinal pathology and neuroanatomical abnormalities (Lewonowski et al., 1992). In these cases, the scoliosis is generally regarded as caused by the pathological abnormalities, as opposed to any putative increased asymmetry. It is not known what, if any implications such abnormalities have for lateralisation.

In addition to the above points, the two studies used very different "control" conditions. Whilst Goldberg et al. compared children with scoliosis to children without, Enslein and Chan compared children with progressive scoliosis to children with non-progressive scoliosis. It is tempting to believe that the latter group had an increased degree of language lateralisation for some reason, and that children with scoliosis therefore appeared relatively less lateralised. However, this does not explain why children with scoliosis appeared to show little lateralisation for language at all.

One further factor that ,may account for the different findings is that the two studies used different techniques for assessing language lateralisation. Although they both used dichotic tasks with fused stimuli, Goldberg et al (1995a) used the FWDT from Wexler and Halwes' (1983). As noted in Section 1.7.2.1.4, this is the only dichotic task that appears to provide an accurate assessment of language lateralisation in individuals when compared to results from the Wada test (Zatorre, 1989). This might suggest that the results of Goldberg et al. (1995a) are perhaps more valid than those of Enslein and Chan (1987), especially when one considers their somewhat larger sample size.

However, it is still difficult to understand why these two studies obtained such radically differing results. The apparent irreconcilability of these findings highlights the need for further research in this complex area. The complexity of the area becomes evident when one contextualises the issue of lateralisation within the developmental instability and maturation literature reviewed above.

1.7.5 Lateralisation, maturation, developmental instability and scoliosis

In the course of her research in this area, Goldberg found early maturation in children with scoliosis (Goldberg, Dowling, & Fogarty, 1993), increased fluctuating and directional physical asymmetry in scoliosis (Goldberg et al., 1995b) and increased directional functional asymmetry in language lateralisation (Goldberg et al., 1995a).

Directional asymmetry is not the only factor out of these that might be associated with differences in lateralisation and functional ability. There is evidence to suggest that fluctuating asymmetry and rate of maturation may also be important.

1.7.5.1 Lateralisation and physical asymmetry in AIS

Goldberg's assertion that increased physical directional asymmetry leads to increased functional directional asymmetry is supported by Foundas et al. (1994) who demonstrated that leftward structural brain asymmetry was associated with left lateralisation of language. This supports the general assumption that structural differences might be reflected in functional differences and the idea that increased directional asymmetry could be associated with increased lateralisation of language.

However, the overall picture is less coherent than this. For example, it is difficult to assess the significance of the literature on directional asymmetry, since Goldberg's findings on directionality seem to have been a little mixed, as she herself commented, although "there are clear associations between cerebral organization and variations in body morphology (in AIS)...there is no simple pattern" (Goldberg & Dowling, 1991, p. 84).

One interpretation of the dichotic listening study could be that people with AIS have increased rightward body asymmetry. and consequently increased lateralisation of language, a predominantly left hemisphere function.. It has been reported that the arm on the convex side of a thoracic scoliosis tends to be longer (Burwell, Dangerfield, & Vernon, 1977)., and most curves are right thoracic (McCarver, Levine & Velaskis, 1971).so logically the increase in arm length will generally be on the right hand side.

However, in many instances, it seems that people with scoliosis may just be exhibiting an increase in directional asymmetry in line with the normal direction of asymmetry;. For example, most people have left hemispheric language and people with scoliosis in the study by Goldberg et al. (1995a) seemed to demonstrate increased lateralisation in language that was generally leftward. In the case of dermatoglyphics, Goldberg found evidence of increased dermatoglyphic directional asymmetry (Goldberg et al., 1995b), but again this was in a normative, rather than consistent direction. being leftward on the a-b palmar index and rightward on the c-d palmar index. In the general population a-b ridges normally exhibit leftward asymmetry and c-d rightward (Jantz & Brehme, 1993).

It seems possible that actually people with AIS are demonstrating simple fluctuating asymmetry and findings of directional asymmetry are simply either random products of a particular samples or perhaps reflect a tendency for disruption to normal development to produce increase asymmetry in a normative direction – the normal direction often being rightward.

That said, it has been claimed that "Developmental instability may result in morphological fluctuating asymmetry on one hand, and lower levels of cognitive ability and functional lateralisation on the other hand." (Rosa et al., 2000, p 132). This would suggest that the findings of both increased fluctuating asymmetry (Goldberg et al., 1995b) and increased lateralisation of language in AIS (Goldberg et al. 1995a) are theoretically mutually incompatible. However, this conclusion appears to have been derived from the results of a study in which negative schizotypal traits were found to be associated with more fluctuating asymmetry and lower cognitive ability in a normal population of adolescents (Rosa et al., 2000). It is not at all clear how the authors came to the above conclusion since they reported finding no significant associations between cognitive ability, behavioural laterality and fluctuating asymmetry.

A study by Yeo et al. (1997) is somewhat clearer. As noted in Section 1.7.3.2, they found an association between increased fluctuating asymmetry and anomalous lateralisation which could account for the findings of both Enslein and Chan (1987) and Goldberg et al. (1995a).

1.7.5.2 Lateralisation and maturation in AIS

The findings from the literature on maturation are also somewhat mixed. As noted in Section 1.6.7.2., early maturation has been linked with increased left ear advantages on lateralisation tasks (Vrbancic, 1994). However, Goldberg found an increased right ear advantage in children with scoliosis and also evidence of earlier maturation in a separate study,

It seems clear that further study of this area is warranted, especially given the potential ramifications for the area of adolescent idiopathic scoliosis.

1.7.6 Significance of research area

The issue of lateralisation in scoliosis may be of interest for several reasons. Firstly, as was noted by Goldberg et al. (1995a), the degree of lateralisation of non-motor cortex functions such as language has implications for theories concerning the aetiology of scoliosis.

Secondly, as previously noted, the location and extent of lateralisation has a number of important practical implications. If the findings of Enslein and Chan (1987) are valid, one might anticipate an increased incidence of difficulties such as dyslexia (e.g. Alejandro-Martinez & Sanchez, 1999) and arguably even schizophrenia (e.g. Bruder & Kaufmann, 1998) in people with scoliosis. If the findings of increased lateralisation from Goldberg et al., (1995a) are valid, the implications are less obvious. There is little evidence to specifically suggest that the increased lateralisation might produce the converse results (i.e. better language skills or decreased incidence of schizophrenia). That said, it is possible that this lack of evidence merely reflects an understandable bias towards studying deficiency, rather than proficiency.

Thirdly, differences in lateralisation might illuminate some of the limited findings of poor academic achievement (Herman et al.,1985) or differences in scholastic strengths and weaknesses (Enslein and Chan, 1987). It is not clear how one might explain the visuovestibular deficits found by Herman et al. (1985) or the particular strength reported by Enslein and Chan (1987) but it is possible that increased levels of fluctuating asymmetry in scoliosis might be associated with either lower ability and/or anomalous lateralisation resulting in differences in academic performance.

Fourthly, differences in degree of lateralisation may have serious consequences for the impact of brain injury, since research suggests that increased lateralisation of language is associated with greater vulnerability to interference by unilateral disruption, whilst less lateralised language is associated with less vulnerability to disruption (Knecht et al.,2002).

As noted by Knecht et al. (2002), people with less lateralisation of language are therefore likely to be less functionally affected by unilateral brain damage such as stroke; conversely those with greater lateralisation are likely to be more affected. If people with scoliosis do have increased or decreased lateralisation of language this may have implications for the neurorehabilitation of people with scoliosis who have suffered unilateral damage. Given the relatively common incidence of scoliosis and cerebro vascular accidents in later life, this is not an insignificant clinical population and hence knowledge about the neuropsychology of people with adolescent idiopathic scoliosis is of relevance to clinical practice.

Finally, understanding the impact of rate of maturation and developmental instability on lateralisation and ability illuminates these areas not only in people with AIS, but also in the general population.

1.8 Current study

As noted, much of the literature reviewed above is contradictory and there only appear to have been a couple of previous studies examining neuropsychological aspects of adolescent scoliosis. It is therefore difficult to make confident predictions concerning neuropsychological functioning in scoliosis. It is clear, however, that further research is warranted in this area as there are a number of theoretical reasons for predicting differences in functioning in scoliosis. This study therefore aimed to address a number of questions concerning this area in scoliosis. It also attempted to assess the relationship between a number of variables in both people with scoliosis and the general population.

As noted, it has been suggested (e.g. Goldberg et al., 1997) that the roots of AIS lie in a combination of developmental instability and an innate tendency to directional developmental destabilisation. These factors lead to an increase in directional asymmetry. Goldberg et al. (e.g. 1997) hypothesised that the addition of the developmental stressor of early maturation during the adolescent growth spurt may lead to the major directional asymmetry of AIS developing in adolescence. This theory is depicted in Figure 1-9.

However, some studies (e.g. Drummond & Rogala, 1980) have suggested that people with AIS may experience relatively later maturation. It is therefore possible that either early or later maturation may be a developmental stressor and thereby lead, in conjunction with increased directional asymmetry, to the development of AIS. The current study consequently makes somewhat different predictions, which are shown in Figure 1-10.

The hypotheses are discussed in depth below, but in brief, the theoretical background is as follows. In line with Goldberg et al. (e.g. 1997), it is hypothesed that the factors that may lead to AIS have consequences of their own that occur independently of AIS. Developmental instability is believed to lead to increased fluctuating asymmetry (e.g. Møller et al., 1997) which has been associated with decreased I.Q. (Furlow et al., 1997). Increased directional asymmetry has been associated with anomalous language lateralisation – specifically increased language lateralisation (e.g. Goldberg et al., 1995a), which may result in better scores on verbal I.Q. tasks

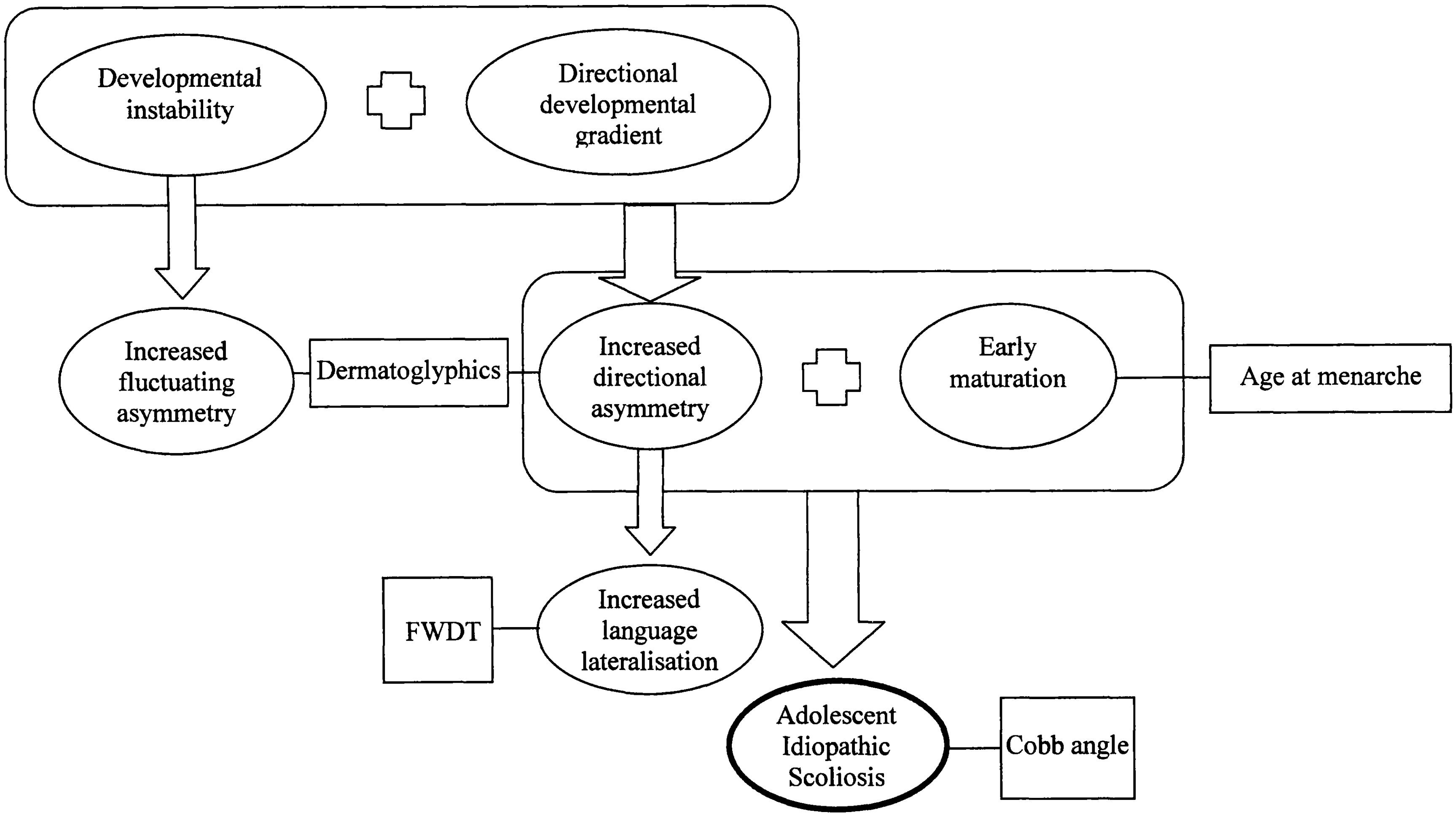


Figure 1-9 The findings and hypotheses of Goldberg et al. (e.g. 1995, 1997)

Key to Figure 1-9 and Figure 1-10

Measure

Construct

Postulated relationship between variables

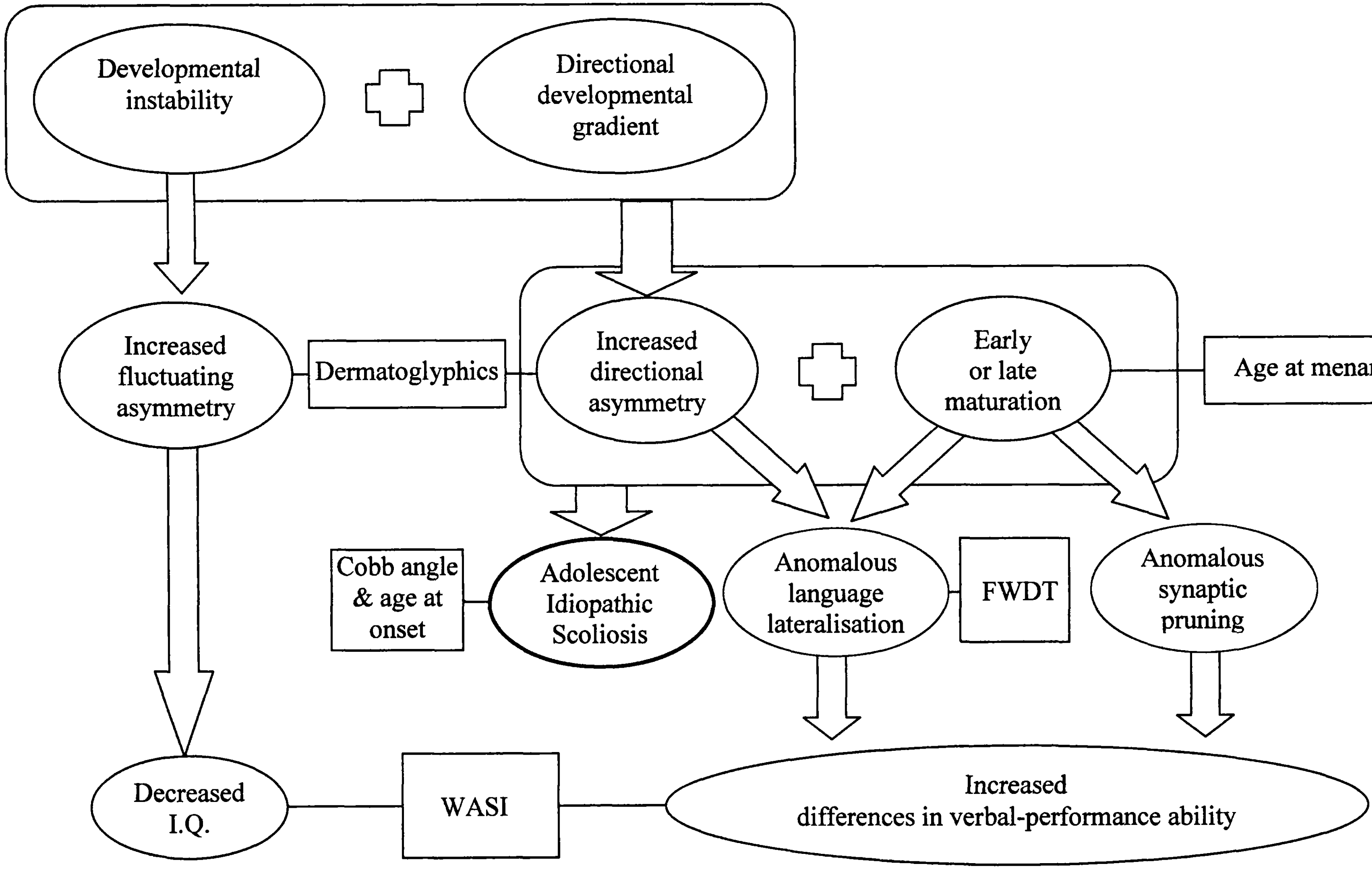


Figure 1-10 Diagram showing possible relationships between variables and constructs

relative to performance. However, there are two reasons why it is not appropriate to predict increased language lateralisation in AIS. Firstly, Enslein and Chan (1987) found decreased language lateralisation in this population. Secondly, it has been suggested that differences in maturation rate may produce differences in lateralisation, with late maturers demonstrating stronger lateralisation than early maturers (Waber, 1976). Although Goldberg et al. (1997) found earlier maturation in AIS, as noted above, Drummond and Rogala (1980) found the opposite so it is not clear whether one might anticipate greater or lesser lateralisation of language. However, both these possibilities might lead to an increase in Verbal-Performance differences. It is concievable that speed of maturation may also affect Verbal-Performance differences via its postulated impact upon synaptic pruning (Saugstad, 1989; 1998), although this study does not attempt to test this particular mechanism.

1.8.1 Is there anomalous language lateralisation in women with adolescent idiopathic scoliosis?

It seems that there are reasonable grounds to suspect that people with scoliosis might have anomalous cerebral asymmetry. To date, of the two studies that have examined language lateralisation, one suggests that there is greater lateralisation of language in scoliosis and one suggests that there is less lateralisation.

It is important to clarify the question of anomalous lateralisation in scoliosis for the reasons delineated above. This study therefore would aim to clarify the situation by examining language lateralisation in women with scoliosis and controls using the same fused word dichotic listening task used by Goldberg et al. (1995a). Given the disparity between Goldberg's results and those of Enslein and Chan (1987), this study only predicts that there will be differences between lateralisation in people with scoliosis and controls.

1.8.2 Is there an increase in directional asymmetry in women with adolescent idiopathic scoliosis?

Goldberg et al. (1995b) found an increase in directional asymmetry in women with AIS and this study would predict similar findings.

1.8.3 Do women with AIS mature earlier or later than those without scoliosis?

Given the heterogeneity of findings concerning age of maturation and scoliosis, it is hard to predict with any certainty whether women with scoliosis will demonstrate earlier or later age of maturation than women without scoliosis. The prediction regarding age of maturation will again necessarily predict differences between people with scoliosis and controls, without predicting the direction of the differences.

1.8.4 Do women with AIS demonstrate differences in their verbal skills relative to their performance skills?

There are several reasons to anticipate differences in performance and verbal skills in AIS. Increases in language lateralisation associated with early maturation are associated with an increased performance:verbal ratio. Kimura's work (e.g. Kimura, 1999) would suggest that if people with scoliosis have increased directional asymmetry relative to people without scoliosis, one might anticipate increased differences in verbal and performance skill relative to controls.

As noted, Herman et al. (1985) reported finding an impairment in visuospatial functioning in people with scoliosis and Enslein and Chan (1987) believed that their scoliosis patients were more skilled at right hemisphere tasks. However, to date there has been no examination of the relative strengths of verbal and nonverbal ability in AIS.

1.8.5 Is there a relationship between rightward physical directional asymmetry and leftward language lateralisation?

Goldberg et al. (1995a; 1995b) have demonstrated both increased left-right physical asymmetry and increased degree of leftward language lateralisation in adolescents with adolescent idiopathic scoliosis. However, this was done in two separate studies and given the apparently heterogeneous nature of adolescent idiopathic scoliosis patients, it would be helpful to directly assess the relationship between these two variables in the same population. One would anticipate that there would be a positive correlation between these variables. Furthermore, one would also predict that this relationship would be demonstrated in people without scoliosis.

1.8.6 Is there a relationship between fluctuating asymmetry and I.Q. ?

Several studies in the literature have suggested that fluctuating asymmetry is inversely correlated with overall I.Q. (e.g. Furlow et al., 1997). There is also some evidence, albeit rather limited, that some children with adolescent idiopathic scoliosis may exhibit what was termed "school malachievement" (Herman et al., 1985). If people with scoliosis do indeed demonstrate higher levels of fluctuating asymmetry and fluctuating asymmetry is also correlated with lower ability, then this might explain the latter observation.

This study will therefore assess the relationship between these two variables and predict that there will be a positive correlation between the two and that this relationship will also be demonstrated in people without scoliosis.

1.8.7 Is there a relationship between age of maturation and differences in verbal and performance skills?

As noted, there is evidence that later age of maturation may be associated with better performance skills (Waber, 1979), with no effect on verbal skills. This study would therefore predict a positive relationship between age of maturation and relative performance skill.

1.9 Hypotheses

The study will therefore address the following hypotheses:

- Hypothesis 1 – There will be differences in the lateralisation of language in women with adolescent idiopathic scoliosis relative to controls.

- Hypothesis 2 – There will be an increase in directional asymmetry in women with adolescent idiopathic scoliosis relative to controls.

- Hypothesis 3 – There will be an increase in fluctuating asymmetry in women with adolescent idiopathic scoliosis relative to controls.

- Hypothesis 4 - There will be differences in age of maturation in women with adolescent idiopathic scoliosis relative to controls.

- Hypothesis 5 – There will be differences in relative verbal and performance ability in women with adolescent idiopathic scoliosis relative to controls.

- Hypothesis 6 - There will be a positive correlation between rightward physical directional asymmetry and leftward language lateralisation

- Hypothesis 7 – There will be a negative correlation between fluctuating asymmetry and I.Q.

- Hypothesis 8 – There will be a positive correlation between age of menarche and better performance skills relative to language skills.

2 Method

2.1 Design

The study was of a matched-pairs design, with each experimental AIS participant being matched with a control, non-scoliotic participant for age (± 5 years), years education (± 2 years) and occupational status, as categorised by the Standard Occupational Classification 2000 (Office of National Statistics, 2000).

2.2 Participants

2.2.1 Power Analysis

A power analysis was performed using data from the previous paper examining language lateralisation and scoliosis (Goldberg et al., 1995a). It suggested that the study would require a minimum of 37 control and 37 experimental participants to have 80% power to detect the effect size of 0.64 (the effect size found in the previous paper), assuming that an independent measures t-test was used, with a statistical criterion of 0.05, two tailed.

2.2.2 Inclusion and Exclusion Criteria

Many studies of adolescent idiopathic scoliosis have been carried out on clinic samples of adolescents still undergoing treatment. The advantage of this is that they are easily accessible and that all the relevant medical data is available. However, they are also still developing. Given the suggestion that the age of maturation may differ in adolescent idiopathic scoliosis relative to controls, comparing adolescents with age matched controls, particularly on neuropsychological measures, may not be appropriate, since results may reflect effects of stage of growth generally, rather than any final impact of age of maturation. Consequently, adults with adolescent idiopathic scoliosis were believed to be more appropriate participants for the current study.

Handedness and gender are known to be related to lateralisation (Eviatar, Hellige, & Zaidel, 1997) and participation in the study was therefore restricted to right handed females. The use of only women also meant that it was possible to use age of menarche as a marker of age of maturation (e.g. Newcombe, Dubas and Baenninger (1989) whereas no such convenient measure is available for males.

For ease of recruitment, participants were deemed as being eligible for the study if they wrote with their right hand. Native language may affect performance on dichotic listening tasks so non-native English speakers were also excluded.

Women with no "c" tri-radii on their palms were excluded from the study, since it was not possible to count from tri-radii b to c or c to d. Similarly, women with any reported history of hearing problems in either ear were excluded since this would impede the auditory measurement of language lateralisation.

2.2.3 Participants with Scoliosis

2.2.3.1 Recruitment of participants with scoliosis

Originally, it was intended to recruit all participants with scoliosis via the Scoliosis Association. However, insufficient numbers were recruited via this route, so a variety of alternative sources were used in addition. Participants were also recruited via a scoliosis genetics study from a local hospital, a scoliosis support site on the internet and through personal contacts.

The Scoliosis Association contacted women with scoliosis and gave them the study information sheet (See Appendix 1). If they were then interested in participating, they gave consent for the researcher to contact them and their details were forwarded to the researcher. In the case of the hospital scoliosis study, letters were sent out via the researchers to women who had participated in their study, including a study information sheet and asking them to complete a reply slip if they were interested in participating. Potential participants were asked to specify if they were right handed, native English speakers with no hearing problems. Participants were recruited from the scoliosis internet support group (www.support4scoliosis.co.uk) by submitting a post to the messageboard, again including the text of the study information sheet and inviting potential participants to e-mail the researcher.

2.2.3.2 Scoliosis Status

The scoliosis status of the participants was self reported. In order to ensure that participants had scoliosis, they were asked what treatment they had and what the degree of their curvature was now. This ensured that they did indeed have significant spinal curvature. Their current curvature would be reduced by any previous treatment, but treatment itself would indicate significant scoliosis since curves under twenty degrees would not be treated.(Clough, 1978).

In order to check that their scoliosis was adolescent in onset, scoliosis participants were asked what age they were when their scoliosis was first noticed. This also provided a more reliable measure of the severity of the condition than the current degree of curvature post treatment, since age of onset is known to be strongly correlated with ultimate curvature (Lonstein, 1999).

2.2.4 Control Participants

2.2.4.1 Recruitment of control participants

Control participants were also recruited from a variety of sources. Some control participants were friends or acquaintances of scoliosis participants, but the great majority were recruited in a pyramid fashion through acquaintances of the researcher or the participants themselves. Each participant in both the control and scoliosis conditions was asked if they knew of any one else who would be eligible for the study and be willing to volunteer. If they did, they were asked to give a study information sheet (See Appendix 2) to their contact and ask them to contact the researcher for further information. When potential participants contacted the researcher, the study was explained in further detail and the participant's eligibility ascertained. If the individual was eligible and willing to participate in the research, they were included in the study.

2.3 Matching procedure

Participants were not matched on the basis of I.Q., since it was hypothesised that there might be differences in verbal and performance I.Q. and therefore I.Q. was not an appropriate matching criterion. Similarly, the National Adult Reading Test (Nelson, 1982) was not used as an alternative since differences it is verbally based.

However, differences between verbal and performance I.Q. vary as a function of overall level of ability (Matarazzo & Herman, 1985), so it was important to match participants on ability in some fashion. Age, years of education and occupational status have been shown to reliably predict overall I.Q. (Crawford, Millar, & Milne, 2001). Participants were therefore matched on these criteria: age (± 5 years), years of education (± 2 years) and occupational status, as categorised by the Standard Occupational Classification 2000 (Office of National Statistics, 2000).

2.3.1 Standard Occupational Classification 2000

The Standard Occupational Classification 2000 (SOC2000) is the measure developed and utilised by the Office for National Statistics to classify occupation. It consists of the following major groups:

1. Managers and Senior Officials
2. Professional Occupations
3. Associate Professional and Technical Occupations
4. Administrative and Secretarial Occupations
5. Skilled Trades Occupations
6. Personal Service Occupations
7. Sales and Customer Service Occupations
8. Process, Plant and Machine Operatives
9. Elementary Occupations

Participants' occupations were categorised into one of these nine major categories by consulting the SOC2000 manual which contains detailed information about categorising particular jobs. The experimental participants were then matched with controls within the same grouping, as well as age bracket and years of education. The SOC2000 does not include a category for students, so experimental participants who were students were simply matched with other students.

2.3.2 Measures:

2.3.2.1 Questionnaire

The questionnaire for control participants contained nine items (See Appendix 3) concerning date of birth, occupation, years education, age at menarche, family and self history of scoliosis and whether the participant had hearing difficulties. The questionnaire for participants with scoliosis included an additional four questions regarding when their scoliosis was first noticed, what treatment they had and what type and degree of curvature (See Appendix 4).

2.3.2.2 Handedness

In order to simplify recruitment, participants were deemed as being eligible for the study in terms of handedness if they wrote with their right hand. However, this is only one aspect of handedness (Verdino & Dingman, 1998). In order to ensure that the two groups contained participants who were equally right handed, a modified form of Annett's (1971) hand-preference questionnaire was used (See Appendix 5), as recommended by Halwes (1991).

Participants were required to indicate whether they used their right, left or either hand to do each of 12 actions. Each response indicating that they only used their right hand for a task scored one point; the total number of points giving an indication of right handedness.

2.4 Assessment of language lateralisation

The FWDT test was obtained from T. Halwes at Precision Neurometrics and consisted of an audio CD of the stimuli (See Appendix 6 for CD tracks), a manual with detailed information on administration and marking software (Halwes, 1991) The test was Canadian in origin, but it had been previously piloted in a British population and found to produce the expected results (Pearce, unpublished).

The test stimuli consisted of 15 stimulus pairs of rhyming, short consonant-vowel-consonant words (See Appendix 7), the stimuli in each pair differing only in their final consonant (e.g. coat/goat). The stimuli were derived from natural speech recordings which were then manipulated so that in each pair the ending portion of the words (e.g. -oat) was identical in terms of sound and onset, with a different initial consonant at the beginning.

The stimuli were presented via an audio CD which was played on a Sony personal CD player (model D-FJ61) through headphones with circumaural cushions. The headphones were Sennheiser HDA 200 and were audiometrically matched. In addition, the circumaural cushions were sound excluding, producing an average reduction of external sound of 45 Db.

The stimuli were presented at 81Db, as recommended by Halwes. In order to achieve this, the volume output of the CD player was assessed using the calibration tone provided on Track 3 of the FWDT cd and a type 2203 Brüel and Kjær SPL meter with a type 4144 microphone cartridge. The meter was set to slow response mode because the calibration signal was an intermittent tone.

Conveniently, it was discovered that if the headphones were plugged into the CD line output socket, the decibel level was a constant, and unchangeable 81 Db. Throughout the experiment, the headphones were therefore plugged into this socket, thus ensuring that the FWDT was presented at the same appropriate volume to all participants.

The FWDT contains two practice trials prior to the dichotic task. In the first practice trial all thirty words are presented one at a time in stereo and the participant is required to check off each word as they hear it on the response sheet. This procedure is to familiarise the participant with the words in the test.

In order to screen for unilateral hearing loss, the second part of the FWDT consists of a 2 page monotic practice section, where each word is presented to one ear at a time and the participant is required to circle one of four possible responses to indicate which word they heard. Halwes (1991) noted that this serves as a hearing screening test in that there is no evidence to suggest that changes in the relative volume of the dichotic signals that are not evident in monotic performance would affect dichotic performance. He also noted when presented at the recommended volume, the FWDT was robust with regard to minor unilateral hearing loss.

In the dichotic part of the trial, both words in each word pair are presented simultaneously, one to each ear and the participant is again required to circle on of four possible responses to indicate which word they thought they heard.

The CD contained 3 different randomisations of the FWDT, randomisations A, B and C. Halwes recommended that to determine lateralisation of language at least two versions of the task should be completed and that the addition of the third version of the task would further increase the number of participants classified as significantly lateralised to one side or another.

Although the CD purchased from Halwes contained the appropriate tracks for the randomisation C, the programs supplied did not include the test keys for analysing data from randomisation C and Halwes was unable to supply this information. The randomisations A and B were therefore presented twice to each participant.

In both randomisations each of the 15 word pairs were presented in pseudorandom order 8 times in total; 4 times with word A in the left ear and word B in the right ear and 4 times with the converse configuration. This made a total of 120 trials per randomisation (15 word pairs X 8 presentations). Given that 2 randomisations were presented twice, each participant completed a total of 480 trials overall (120 trials X 4 randomisations).

2.4.1 Determination of language lateralisation scores

Although it has been argued that the FWDT is superior to other dichotic listening tasks, it is also more susceptible to the confounding effects of stimulus dominance (Repp, 1977). Stimulus dominance refers to the situation where one stimulus is intrinsically more salient than another because of increased word frequency or its particular phonetic characteristics. If a participant generally reports hearing one word out of a particular pair of words, irrespective of the ear in which it is presented, this is clearly unlikely to provide any useful information about ear dominance and therefore language lateralisation.

In order to counter the effects of stimulus dominance, Grimshaw, Bryden and Finegan

(1995) proposed that FWDT data be analysed using log linear analysis to obtain an index of ear dominance (λ^*) that was independent from stimulus dominance.

In order to obtain $z\lambda^*$, the responses from the FWDT were coded 1,2,3 or 4, depending on whether the participant marked the first, second, third or fourth word on each line of the response sheet (See Appendix 8). These coded responses were entered as a text file in the appropriate format for the companion marking program, "Frugal". Frugal compares participants' responses with a data file containing information on the stimuli presented and the lateralisation of presentation for each stimulus. This program then outputs data files that code correct responses for ear of presentation. These files can then input to SPSS and a log linear analysis conducted.

Log linear models examine interactions between variables to reveal the statistical dependence between them. In this instance, for example, an interaction between response and ear of presentation indicates that response is dependent of ear of presentation and therefore reflects ear dominance. In contrast, an interaction between pair and response suggests that different word pair elicit different responses and therefore reflects differing stimulus dominance (Grimshaw, Bryden, & Finegan, 1995). In order to assess these effects, a number of log linear models are fitted to the data to obtain a measure of goodness of fit of each model.

The first model fitted to the data includes all effects, save the interaction between response and ear of presentation. It thus includes the main effects of pair, response, ear of presentation and the interactions between pair x response and pair x ear of presentation. This gives a likelihood ratio chi-square value for the model measuring goodness of fit.

The second model fitted to the data includes all the effects in the first, with the addition of the critical response x ear of presentation interaction (i.e. ear dominance). Grimshaw et al. note that if this interaction is significant, the change in the measure of goodness of fit will be significant.

In order to obtain measure of ear dominance that is independent of stimulus dominance, a series of parameter estimates are produced for each effect. λ^* is the name given by Grimshaw et al. to the parameter estimate for the response x ear of presentation interaction. : They describe is as being the "log-odds ratio of right-ear responses to left-ear responses after stimulus dominance has been statistically controlled" (Grimshaw et al., 1995, p. 281).

They recommended dividing λ^* by it's standard error to obtain $z\lambda^*$. This gives a value with approximate normal distribution, whose significance can be easily ascertained; a value of $z\lambda^*$ greater than 1.96 (1 s.d.), for example, being significant at $p=0.05$. Significant positive values of $z\lambda^*$ indicate significant right ear advantages and significant negative values indicate significant left ear advantages.

2.5 Dermatoglyphics

As noted above, Goldberg et al. (1997) used dermatoglyphics to assess developmental instability in girls with AIS by comparing the number of lines of the right and left hands of participants, quantifying them using the methodology outlined by Cummins and Midlo (1961).

The same procedure was used in the current study. The experimenter was trained in print taking by a City of London police fingerprint expert using the standard Scotland Yard procedure (Cherrill, 1954). The procedure involved placing an inkstrip (obtained from K9 Scene of Crime, Equipment Ltd., Northampton) on the participant's hand and then rolling over the strip with a roller, so as to deposit an even layer of ink on the participant's hand. Their hand was then placed palm down on an A4 sheet of paper with a cylindrical roller beneath and rolled backwards to create a palmar impression on the paper. This was repeated as many times as was necessary to obtain a clear print of each hand.

In order to assess the differences between palms, the tri-radii on each palm were identified. An example of a tri-radius can be seen in Figure 2-1..

Figure 2-1 Enlarged tri-radius print

Figure 2-2 Palm print with identified tri-radii - a,b,c,d.

Conventionally, the palmar tri-radii are labelled a to d, from the thumb to the fourth finger. These points were identified on each palm and then ridge counts between the tri-radii were counted by a marker blind to both the experimental hypotheses and the status of each palm print (i.e. control or experimental group).

There is also another tri-radius on the hand that can be used for assessing asymmetry. This is the tri-radius "T" at the bottom of the hand, near the wrist. It was intended to also identify this tri-radius and take the angle between it and the tri-radii a and d, as Goldberg at al. (1995b, 1997) did. However, pilot testing indicated that this tri-radius was very difficult to find on many adults, as they have increased depth of creases at the wrist joint. This measure was therefore not used.

Following the procedure used by Goldberg, an asymmetry index was calculated for each measurement using the equation (R-L)/(0.5x(R+L)) (Palmer & Strobeck, 1986), which gives the difference between the two ridge counts as a proportion of the mean ridge count for an individual.

This index assessed the degree of directional asymmetry between the two hands, the sign of the resulting value indicating the direction of the asymmetry. Thus, a positive value indicated more ridges on the right hand and a negative value indicated more ridges on the left hand. In order to examine the degree of asymmetry, irrespective of direction (i.e. fluctuating asymmetry), the absolute value of this figure was used.

2.6 Psychometric Measure

As noted above, there are some measures that have been associated with directional asymmetry, albeit not particularly reliably (e.g. Kimura & Carson, 1995) (See Section 1.6.6.2.1). However, these measures have been American tasks that are not in clinical usage in the U.K. Similarly, tasks used to assess the impact of fluctuating asymmetry on intelligence (Furlow et al. 1997).have also been ones that are rarely used in Britain.

It was felt that for the results to be of relevance in a British clinical setting, it would be important to assess whether any of the variables examined in this study had an impact upon measures commonly used by clinical psychologists in the U.K.

The Wechsler Adult Scale of Intelligence (WAIS) is the most widely used I.Q. tests in the U.K., as well as worldwide (e.g. Kaufman, 1990). However, the administration of the task takes at least an hour and was judged to be too lengthy when administered in addition to the other experimental tasks. The Weschler Abbreviated Scale of Intelligence (Psychological Corporation, 1999) was therefore chosen as an appropriate compromise between brevity and utility.

The Weschler Abbreviated Scale of Intelligence (WASI) is a relatively new addition to the stable of Weschler I.Q. tests. It consists of 4 subtests: Vocabulary and Similarities (the verbal tasks) and Block Design and Matrix Reasoning (the performance tasks). All of these subtests are taken from the WAIS, although the content differs slightly.

The Vocabulary subtest contains 42 vocabulary questions where the person being tested is required to provide a definition for each word. In the Similarities sub-test, there are 26 items where the person must tell the examiner in what way two words are similar. The Block Design task requires the individual to reproduce a series of 13 two dimensional designs, using a number of patterned blocks. Scores in this sub-test also reflect the speed of response, as well as whether it was correct. Finally the Matrix Reasoning task requires the participant to chose the appropriate visual stimulus to complete a given pattern, the trials numbering 35 in total.

The WASI provides age scaled normative scores for all subtests from which one can calculate both full scale I.Q. and Verbal and Performance I.Q. One of the major advantages of using a test like this is that one can therefore easily compare ability across these two domains.

The WASI takes about 30 minutes to administer and the manual gives full guidelines for administration. It also gives strict guidelines for scoring to minimise the possibility of any bias in scoring. The WASI was not blind marked since the administration procedure necessitates some marking during the administration of the test and it was felt that there was minimal possibility of any experimenter bias affecting the results because the marking criteria were so narrow.

2.7 Ethical approval and Consent

Ethical approval for the study was granted by the Joint UCL/UCLH Committees on the Ethics of Human Research. A copy of the approval letter is in Appendix 9. Signed consent was given by all participants, on the consent form recommended by the Ethics Committee. A copy of the consent form can be found in a Appendix 10.

2.8 Procedure

The study was conducted in the participants' homes, with two exceptions (one scoliotic and one control participant) who completed the study in a university laboratory.

Participants were advised prior to participation that the study would require the use of a table in a room where they would not be disturbed for at least a couple of hours.

The appropriate study information sheet was given to all participants prior to obtaining informed consent. Copies of the study information sheets for people with scoliosis and controls can be found in Appendix 1 and Appendix 2.

When participants had read the information sheet, they were asked if they had any questions. If they did, these were answered before giving them the consent form to sign, a copy of which can be found in Appendix 10.

After consenting to participate, participants were given the appropriate questionnaire to complete (See Appendix 3 and Appendix 4 for copies of questionnaires). After finishing this, participants were told that they were going to be doing a task that would assess the way that they processed language.

Participants were shown the first FWDT response sheet, a list of thirty words. They were told that they would hear these words being read in the order of presentation by a male voice and that they were simply required to tick each word as they heard it. They were told that the purpose of this task was to allow them to become familiar with the sound of the words, particularly as the reader had a Canadian accent.

The participants were then shown the headphones which were red on one side and blue on another. The participants were told that the positioning of the headphones (ie. Red headphone on right ear or vice versa) was an important part of the experiment and that at the end of certain pages they would be asked to swop the headphones around (See Appendix 6 for a list of CD track and headphone position). To begin with, they were asked to put the red headphone on their right ear and participants with long hair were asked to tuck their hair out of the way so that no hair was present between the headphones and their ears.

The appropriate track on the CD was then played (See Appendix 6 for a list of track contents) and participants completed the task.

Participants were then told that the next two pages of the task consisted of a practice trial and were shown the first response page (See Appendix 8 for an example). This response sheet, and indeed the response sheets for the rest of the trial consisted of 30 lines of text, with 4 words per line. Participants were told that from this point onwards in the task they would be required to select the word that they heard from one of four words on each line. They were asked to indicate which word they heard by crossing through the appropriate word.

The stimuli for the first page were then played over the headphones and the participants completed their task. At the end of the first page, they were asked to swop the headphones around so that the red headphone was on their left ear.

At the end of the second page, participants were told that in the next part of the task they might find the words more difficult to hear, but that if this was the case, that they were not to worry; it was part of the task. If they were unsure about which word they heard, they were instructed to make the best guess that they could from the four alternatives presented.

Participants then completed the FWDT as described in Section 2.4., with the headphones being swopped around at specific points throughout the task as specified in the manual At the end of the two randomisations, which constituted 8 pages of trials in total, the participants were told that they were now going to do something different, but that there would be some more of the listening task to do at the end of the study. The FWDT was split up in this way to avoid any effects of fatigue upon accuracy.

The experimenter then administered the Wechsler Abbreviated Scale of Intelligence to participants. After this, participants were given the handedness questionnaire to complete and then the second part of the FWDT was completed. Finally, participants' palm prints were taken as described above. In total, testing took an average of two hours per participant.

3 Results

3.1 Description of participants

In total, 74 female right-handed native English speakers completed the study. Half of these participants (the experimental group) had a diagnosis of adolescent idiopathic scoliosis (i.e. onset of scoliosis after age 10 and curvature over 10 degrees) and half (the control group) had no diagnosis of any form of scoliosis or known family history thereof.

3.1.1 Recruitment

As noted in Section 2.2.3.1, participants with scoliosis were recruited from a variety of sources. The number of participants obtained from each source can be seen in Table 3-1 below.

Source	No. people contacted	No. of responses	Exclusions	No. of participants
Scoliosis Association	Unknown	12	0	12
Genetic Study	39	20	4	16
Internet Site	Unknown	8	2	6
Acquaintances	3	3	0	3
Total	-	**43**	**6**	**37**

Table 3-1 Participant Recruitment

Sixteen of the 37 participants with adolescent idiopathic scoliosis were recruited via a study from a South London hospital, examining the genetic causes of scoliosis. Thirty nine letters were sent out by the genetics researcher and 20 responses were received. Four women were not included in the study. One was uncontactable, having changed address, 1 had tinnitus, 1 was left handed and 1 lived in the highlands of Scotland.

The 21 other participants with scoliosis were recruited from a variety of sources. Twelve were recruited via a contact from the Scoliosis Association UK, 2 were acquaintances of the researcher, 1 lived in the same house as a control participant and 6 were recruited via a scoliosis website (Support4Scoliosis.co.uk). Eight people responded to the post on the latter website, but 2 were excluded, 1 because they had congenital scoliosis and 1 because she was working abroad during the data collection period. The final thirty seven experimental participants had a wide geographical spread, being located as far South West as Southampton and as far North East as Hull.

3.1.2 Demographic Information

3.1.2.1 Mean Age

The age of the scoliosis participants ranged from 18 to 70 with a mean of 39.0 (s.d.13.4).The age of the control participants ranged from 20 to 65 with a mean of 38.5 (s.d.13.7).

3.1.2.2 *Ethnicity*

Thirty six out of the 37 participants in each group were Caucasian. The remaining two participants (one per group) were of Asian ethnic origin.

3.1.2.3 *Education*

The mean number of years of education in the scoliosis group ranged from 10 to 21 with a mean of 15.6 (s.d.2.7).The mean number of years of education in the control group ranged from 11 to 22 with a mean of 15.9 (s.d.2.7).

3.1.2.4 *Social Classification*

Distribution of occupations in the scoliosis and control groups is shown in Figure 3-1.

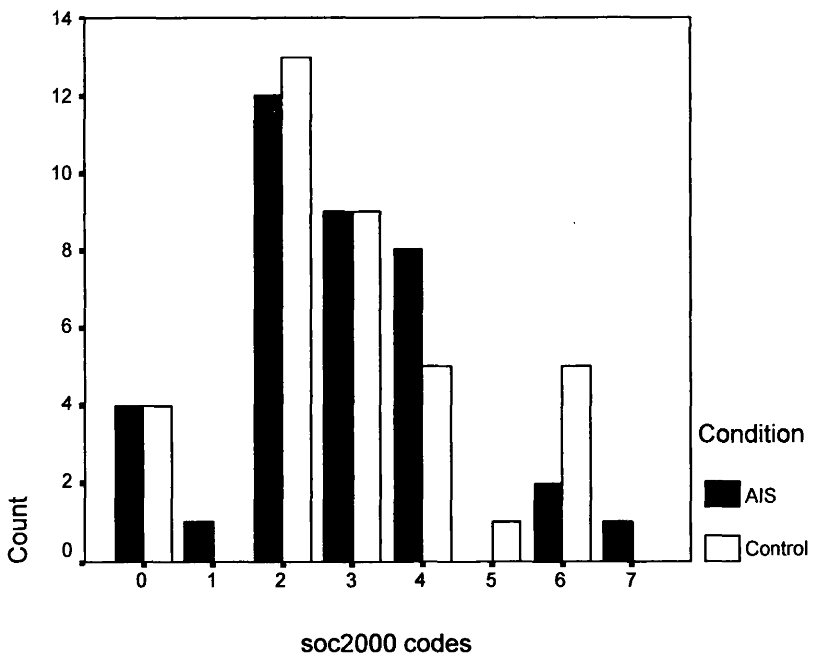


Figure 3-1 Distribution of Occupations

3.1.3 Handedness and Hearing

No participants reported hearing difficulties and none were found on the monotic practice section of the FWDT. All participants wrote with their right hand. Scores on the Annett Handedness Questionnaire (See Section 2.3.2.2) for participants with scoliosis averaged 11.43 (s.d. 1.23), with a range of 7 – 12. Participants without scoliosis averaged 11.32 (s.d.1.24), with a range of 8 – 12.

3.1.4 Differences between Control and Scoliosis group

The control and scoliosis group were compared in order to ensure that they did not differ on age, years education or social classification. Although this necessitated the use of multiple tests, a p-value of $P<0.05$ was chosen to ensure that any potential confounds were not overlooked.

T-tests showed that there were no significant differences between the scoliosis and control group in terms of age ($t(37) = 0.18$; $p=0.86$), years of education ($t(37) = -0.56$; $p = 0.58$), degree of right handedness ($t(37) = 0.37$, $p = 0.71$). Chi Squared analysis demonstrated no significant differences in social classification across the two groups ($\chi^2(7)=5.0$, $p=0.65$).

3.1.5 Scoliosis Variables

3.1.5.1 Curvature

Participants were asked to report their type of curvature (e.g. right thoracic). Unfortunately, only 8 out of the 37 participants were aware of their curvature. These 8 all reported having right thoracic curvatures. It is likely, given the relative incidence of types of curvature and the strong correlation with handedness (Goldberg & Dowling, 1990) that the majority of the participants , being all right handed also had right thoracic curvatures.

The average degree of curvature reported by scoliosis participants was 55 degrees (s.d. 19.2), ranging from 20 to 90 degrees.

3.1.5.2 Age of Onset of Scoliosis

Age of onset was assessed to ensure that participants had adolescent idiopathic scoliosis The mean age at which participants reported that their scoliosis was first noticed was 13.41 on average (s.d.2.28), ranging from 10 to 19 years of age. These figures are consistent with adolescent idiopathic scoliosis.

3.1.5.3 Treatment

Participants reported a variety of treatments, occurring either in adolescence or adulthood, as seen in Table 3-2.

Age at treatment	Brace	Brace & traction	Brace & Fusion	Fusion	Physio, costeoplasty & fusion	Physio	Heat Lamp	None
< 18 yrs	6	1		5			-	-
> 18 yrs	-	-	2[a]	6	1		1	-
Total	**6**	**1**	**5**	**11**	**1**	**4**	**1**	**8 (1 awaiting fusion)**

[a] Brace treatment as adolescent, fusion as adult.

Table 3-2 Treatment for Scoliosis

As noted above, there were 8 participants with scoliosis who had received no treatment for their condition. It might be thought that this could indicate that they did not have significant scoliosis, however, their average degree of curvature was 51.4 (s.d. 17.3), so this was clearly not the case.

3.1.5.4 Family history

Twenty of the 37 participants with scoliosis had a family history of the condition, with at least one family member having had scoliosis. None of the control participants had any family history of scoliosis. Given that some participants were recruited via a genetics study, family history is reported as a function of recruitment source in Table 3-3. As can be seen, only half of the participants recruited from the genetics study reported a family history and this figure was fairly consistent with the proportion of participants from other recruitment sources reporting a family history of scoliosis.

This suggests that the extent of family history in this sample was probably not significantly affected by the inclusion of recruits from a genetic study of scoliosis.

Recruitment Source	No. of participants	No. with family history	Family history as proportion of sample
Acquaintances of researcher	2	1	0.5
Acquaintance of control participant	1	0	0
Scoliosis Association	12	9	0.75
Genetic Study	16	8	0.5
Internet Site	6	2	0.33
Total	**37**	**20**	**0.54**

Table 3-3 Family history of scoliosis as function of recruitment source

3.1.6 Hypothesis Testing: Data Analysis

SPSS version 10 was used to analyse the data throughout.

Møller and Swaddle (1997) report that although asymmetry data often violate assumptions of normality, parametric tests have often been used to analyse such data. It has been argued that parametric statistics can be highly robust to deviations from normal distribution and that parametric tests provide more powerful tools for the analysis of asymmetry data. (Gangestad & Thornhill, 1997).

Parametric techniques were therefore used with the asymmetry data, irrespective of normality of distribution. However, parametric tests are very sensitive to outliers, so all variables analysed using parametric tests were checked for outliers using z-scores. This checking process was only reported if outliers (i.e. data more than 3 s.d. from the mean) were identified.

Multiple tests were used and the risk of a Type 1 error therefore increased. However, the Bonferroni correction was not utilised because it was felt that it was important to retain as much power as possible. P values reported are for 2 tailed significance.

3.1.7 Hypothesis Testing: Scoliosis vs. Controls

3.1.7.1 Hypothesis 1 – There will be differences in the lateralisation of language in women with adolescent idiopathic scoliosis relative to controls.

Lateralisation of language was measured using the fused word dichotic listening task. This is described in detail in Section 2.4. Log linear analysis to obtain the measure of language lateralisation $Z\lambda^*$ was carried as described in Section 2.4.1.

As noted in Section 2.4.1, an ear advantage is significant ($p<0.05$) if the absolute value of $Z\lambda^*$ is greater than 1.96 (1 s.d. from the mean). If $Z\lambda^*$ is positive, this indicates a right ear advantage, if negative, this reflects a left ear advantage.

Significant Zλ* for both groups were identified and 10 significant right ear advantages were found in the scoliosis group, whilst 14 significant right ear advantages were found in the control group. The finding that all significant Zλ* in were positive and indicative of a right ear advantage and language lateralised to the left hemisphere was consistent with the fact that all participants were right handed.

The difference between the number of significant ear advantages detected in each group was analysed using a Chi Squared test. The difference was found to be non-significant ($\chi^2(2)=0.987$, $p=0.32$), suggesting that there was no difference between the number of significant ear advantages found in people in scoliosis compared to controls.

Although relatively few values were significant, most values of Zλ* were positive, again suggesting a right ear advantage and left hemisphere language lateralisation The frequency histograms in Figure 3-2 and Figure 3-3 ably illustrate the directional asymmetry of the ear response, with a normal distribution, but a mean greater than 0 (Van Valen, 1962).

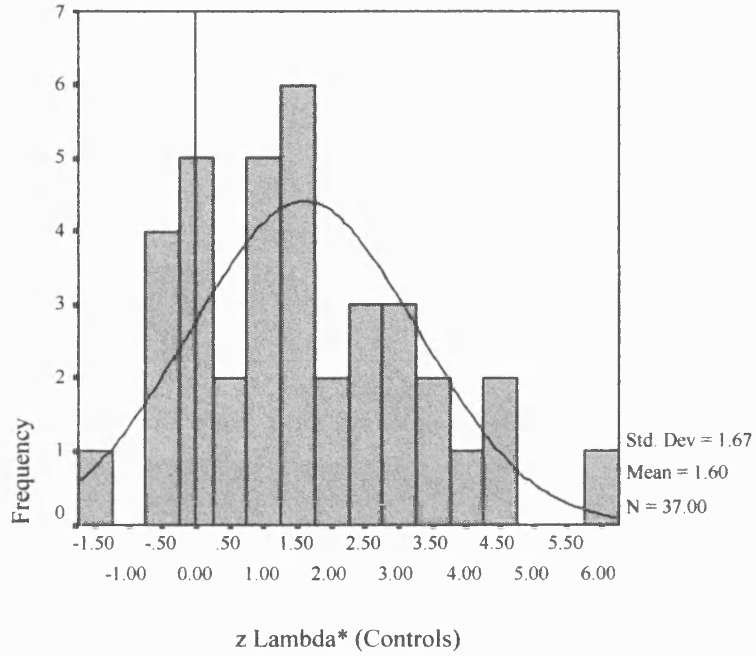


Figure 3-2 Frequency graph of Zλ* for Controls.

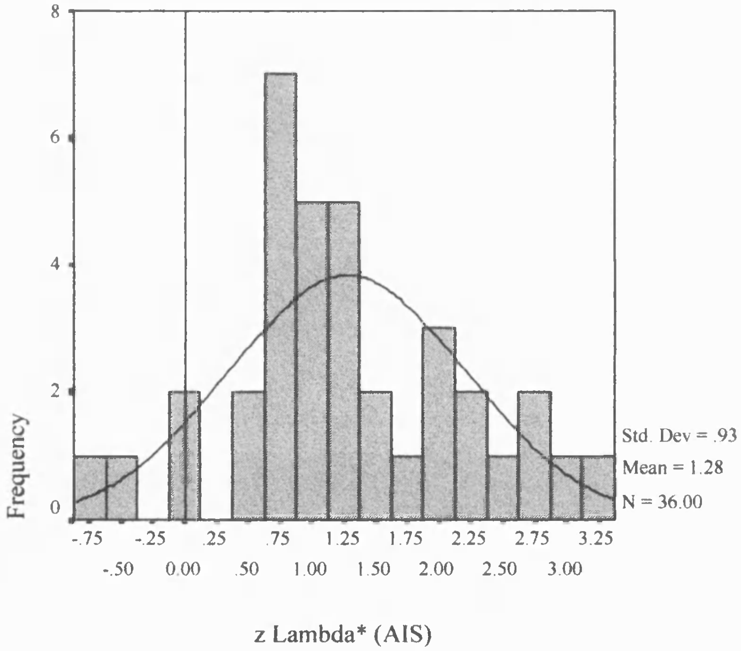


Figure 3-3 Frequency graph of Zλ* for AIS.

This suggested, given that all participants were right handed, that the FWDT was detecting language lateralisation appropriately in British participants, although perhaps not with as much sensitivity as in North Americans.

The hypothesis was therefore evaluated by looking for differences in language lateralisation between the groups, irrespective of whether or not they were statistically significant.

$Z\lambda^*$ in the control group averaged 1.60 (s.d. 1.67) and ranged from –1.26 to 5.86. The scores were normally distributed. $Z\lambda^*$ in the scoliosis group averaged 1.36 (s.d. 1.09) and ranged from –0.87 to 4.25. These scores were also normally distributed.

The variance was significantly different between the groups, so the Mann-Whitney non-parametric test was used to analyse the data. The difference between mean lateralisation of language for people with scoliosis and those without scoliosis was not significant. ($U=64$, $N_1 = 37$, $N_2 = 37$, $p=0.662$). The hypothesis that people with scoliosis would have different lateralisation of language compared to controls was not supported.

3.1.7.2 Hypothesis 2 – There will be an increase in directional asymmetry in women with adolescent idiopathic scoliosis relative to controls..

Directional asymmetry was assessed using dermatoglyphic measures, the means and standard deviations of which are shown in Table 3-1.

Area counted	Interdigital Areas					
	Controls			AIS		
	a-b	b-c	c-d	a-b	b-c	c-d
Right hand	39.0	26.0	33.1	39.6	28.6	36.2
	(5.1)	(5.2)	(10.2)	(6.0)	(5.5)	(6.3)
Left hand	38.7	26.4	31.65	42.05	27.2	36.2
	(5.2)	(5.2)	(9.8)	(7.3)	(5.6)	(6.7)
Total count	77.7	52.4	64.7	81.7	55.8	72.4
R-L	0.22	-0.41	1.41	-2.41	1.4	-0.54
asymmetry[a]	(3.1)	(4.6)	(7.47)	(6.8)	(3.9)	(5.22)

[a] Means for right hand and left hand counts are to 2 decimal places; figures for mean R-L asymmetry are based on original data; hence the apparent discrepancies between means for right hand and left hand, and R-L asymmetry

Table 3-4 Mean (s.d.) interdigital ridge counts as a function of group

Three proportional indices of ridge count asymmetry between the tri-radii a-b, b-c and c-d, were derived from the participants' palm prints, as described in Section 2.5. A negative number indicated that there were a greater number of ridges on the left side than the right. A positive number reflected a greater number of ridges on the right palm when compared to the left. The larger the absolute number, the greater the asymmetry. The means and standard deviations for the proportional indices of asymmetry can be seen in Table 3-5.

	A-B	B-C	C-D
Scoliosis Group	–0.055 (0.16)	0.033 (0.135)	0.002 (0.15)
Control Group	0.006 (0.79)	–0.016 (0.189)	0.060 (0.31)

Table 3-5 Mean indices of dermatoglyphic asymmetry as a function of group

3.1.7.2.1 A-B index

The a-b index in the control group averaged 0.006 and ranged from –0.12 to 0.16. (See Figure 3-4) The a-b index in the scoliosis group averaged –0.055 and ranged from –0.49 to 0.32 (See Figure 3-5).

As can be seen from the histogram, these scores appear to demonstrate a leftward skew. The variance was also significantly different between the groups, so the Mann-Whitney non-parametric test was used to analyse the data.

The difference in directional asymmetry between the two groups was significantly different ($U=499$, $N_1 = 37$, $N_2 = 37$, $p=0.045$). This supports the hypothesis that there would be increased directional asymmetry in people with scoliosis relative to controls.

3.1.7.2.2 B-C index

The b-c index in the control group had a mean of –0.016, with a range of –0.43 to

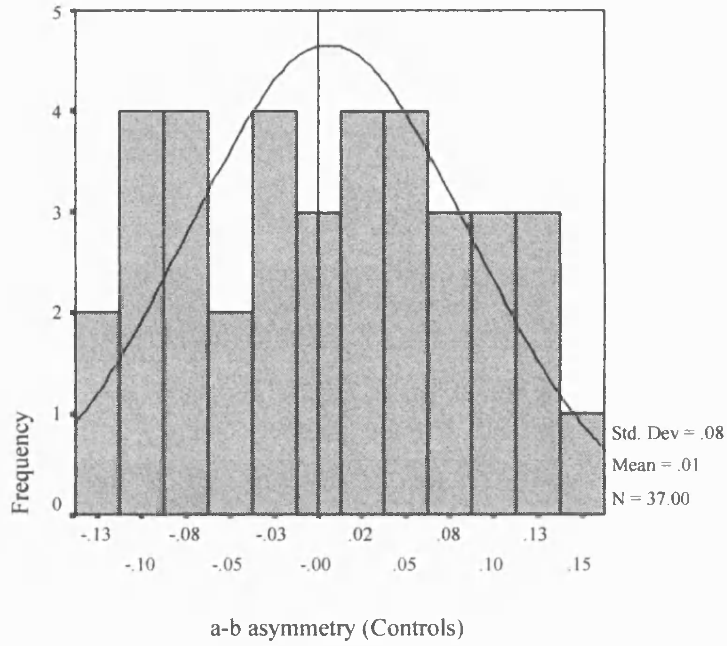


Figure 3-4 Frequency histogram of a-b for controls

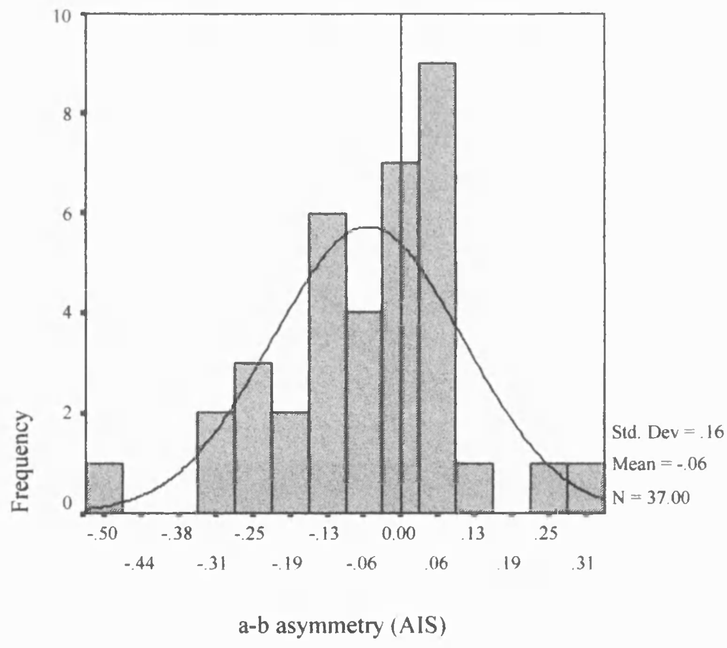


Figure 3-5 Frequency histogram of a-b for AIS

0.50. The data was not normally distributed (See Figure 3-6). There was one outlier in the scoliosis group and her data was therefore eliminated from this analysis. The b-c index in the scoliosis group had a mean of 0.033, with a range of –0.31 to 0.40 (See Figure 3-7).

The difference between the two groups was not significant (t (71) = 1.33, p=0.187). This does not support the hypothesis that there would be increased directional asymmetry in people with scoliosis relative to controls.

3.1.7.2.3 C-d index

The c-d index in the control group had a mean of 0.060, with a range of –0.80 to 0.8. It was not normally distributed (See Figure 3-8). The c-d index in the scoliosis group had a mean of 0.002, with a range of –0.3 to 0.32. It was normally distributed (See Figure 3-9). The variance was significantly different between the groups, so the Mann-Whitney non-parametric test was used to analyse the data.

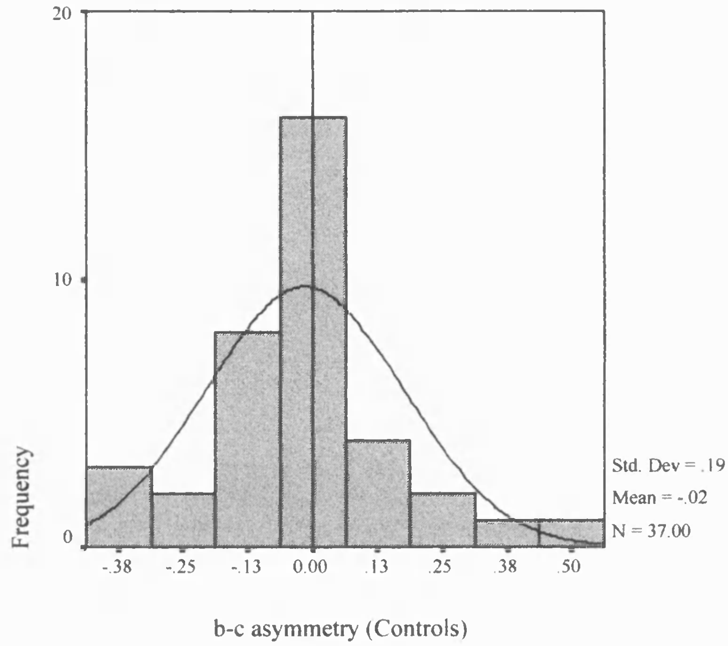


Figure 3-6 Frequency histogram of b-c for controls

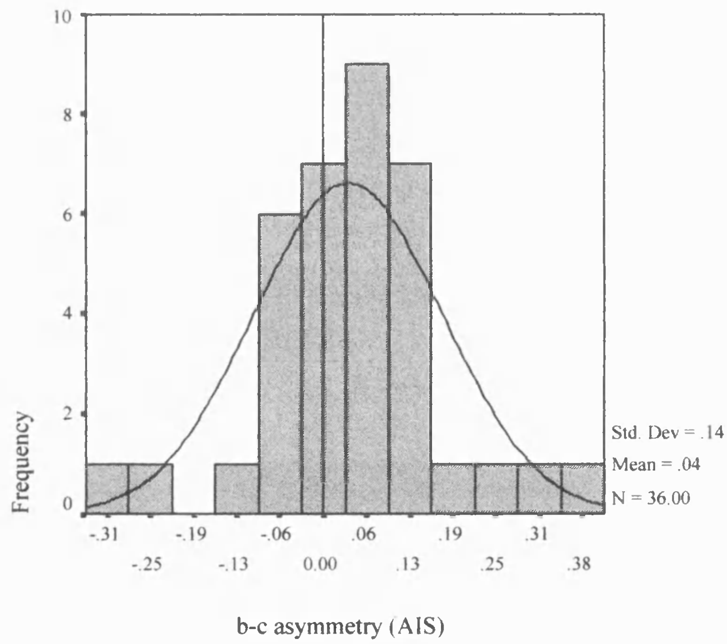


Figure 3-7 Frequency histogram of b-c for AIS

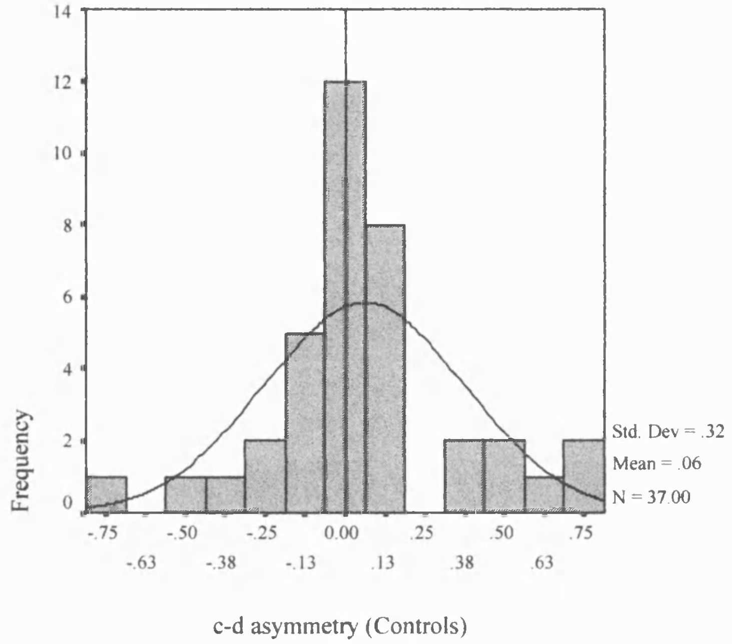


Figure 3-8 Frequency histogram of c-d for controls

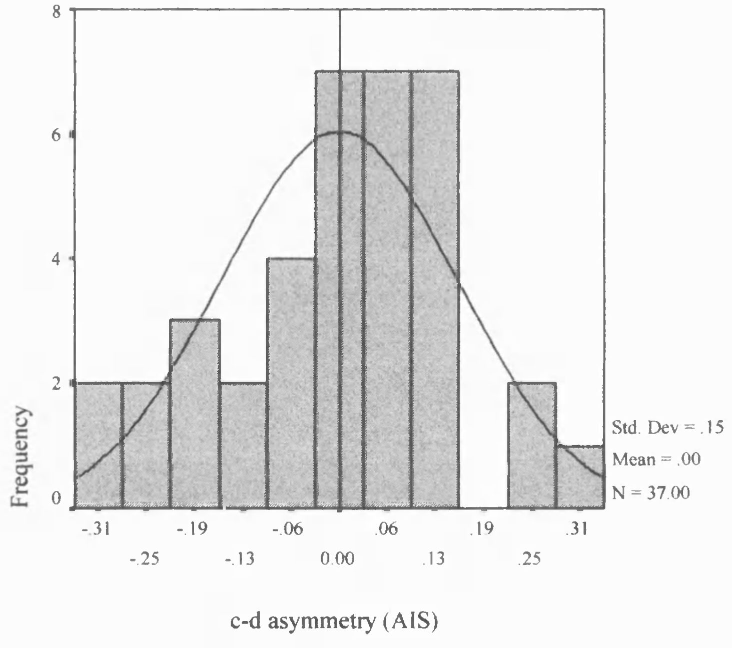


Figure 3-9 Frequency histogram of c-d for AIS

The difference between the two means was not significant (U=592.5, N_1 = 37, N_2 = 37, p=0.320). The hypothesis that people with adolescent idiopathic scoliosis would have higher directional asymmetry than controls was therefore not supported.

In conclusion, it seems that directional asymmetry was only significantly increased in people with scoliosis relative to controls on the palmar area a-b. The directional asymmetry was leftward.

3.1.7.2.4 Differences in total ridge count

As can be seen from Table 3-4 it seems that the AIS group have a greater total number of palmar ridges compared with controls. In order to ascertain if this difference was significant, ridge counts for all 3 interdigital areas were summed for each group.

There was one outlier in the Control group whose data was therefore excluded from this analysis. The total mean count for a-d for Controls was 197 (s.d. 25.31) and the data were normally distributed. The total mean count for a-d for AIS was 209.91 (s.d. 24.40) and again the data were normally distributed.

Analysis using an independent measures t-test demonstrated that this difference was significant (t (71)= 2.22, p=0.03). This suggests that although there was limited evidence to support the hypothesis of increased directional asymmetry in women with

AIS, women with AIS did seem to have an increased total ridge count, compared to controls.

3.1.7.3 Hypothesis 3 – There will be an increase in fluctuating asymmetry in women with adolescent idiopathic scoliosis relative to control participants

Fluctuating asymmetry was measured by taking the absolute value of the signed proportional difference between the interdigital measures on the left and right hand (e.g. Rosa et al., 2000). The resulting variable, ΣFA, thus gives a measure of the variance of the data and therefore the extent to which asymmetry fluctuates from left to right. The absolute values for the 3 measures for the interdigital areas a-b, b-c and c-d were summed because composite scores of fluctuating asymmetry have been found to be a more valid measure of fluctuating asymmetry (Pechenkina et al., 2000).

Mean ΣFA in the control group was 0.42 (s.d. 0.305) (See Figure 3-10) and mean ΣFA in the AIS group was 0.34 (s.d. 0.207) (See Figure 3-11). This difference is in the opposite direction to that predicted by the hypothesis, in that on average, control participants demonstrated more fluctuating asymmetry than people with scoliosis. The variances of the two groups were significantly different and therefore the Mann Whitney non-parametric test was used to assess the significance of this difference. The difference between the two means was not significant ($U=629$, $N_1 = 37$, $N_2 = 37$, $p=0.549$). The hypothesis that people with adolescent idiopathic scoliosis would have higher fluctuating asymmetry than controls was not supported.

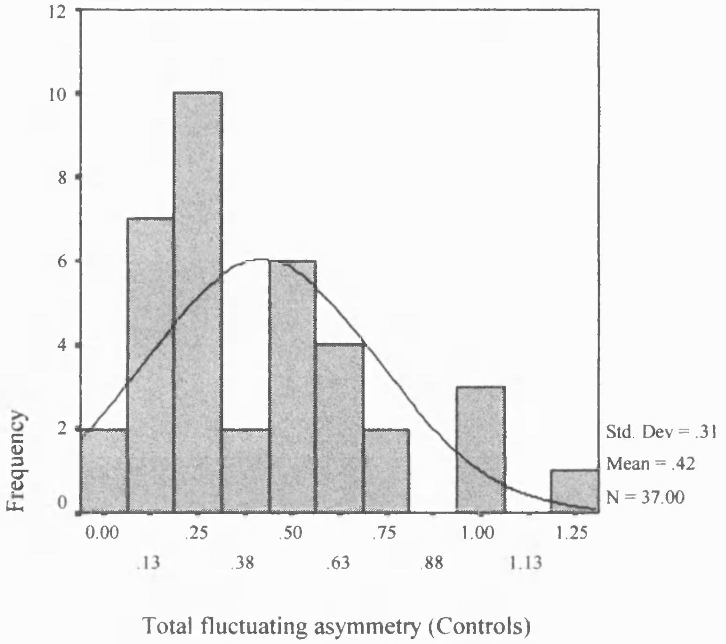


Figure 3-10 Frequency graph of fluctuating asymmetry for controls

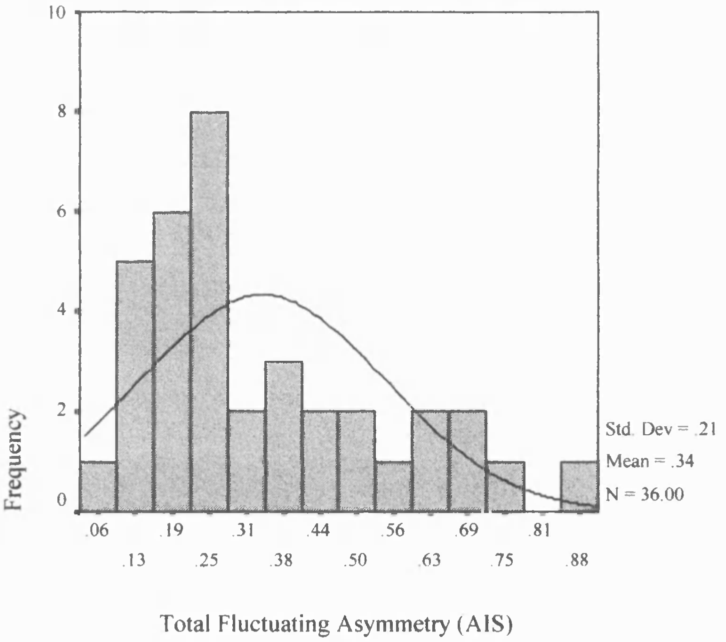


Figure 3-11 Frequency graph of fluctuating asymmetry for AIS

3.1.7.4 Hypothesis 4 – The age of maturation of women with adolescent idiopathic scoliosis will be different from that of control participants

In participants with scoliosis, the mean reported age of menarche was 13.45 (s.d. 0.27), and ranged from 9 years to 17 years. This variable was normally distributed. In control participants, the average age of first menarche was 12.87 (s.d. 0.31) and ranged from 9 to 16 years. These values were also normally distributed.

The difference between the two groups was not significant ($t(72) = 1.39$, $p=0.17$). This does not support the hypothesis that there would be differences in age of maturation in women with scoliosis compared to controls.

3.1.7.5 Hypothesis 5 – There will be differences in relative verbal and performance ability in women with adolescent idiopathic scoliosis compared to controls.

Relative skills scores were calculated by subtracting participants' performance scores from their verbal scores on the WASI. A negative value therefore indicated that performance scores were higher than verbal scores and vice-versa.

The resulting difference scores in the scoliosis group averaged –7.5 (s.d. 9.5, range -33 to 10). The difference scores were normally distributed. In the control group, difference scores averaged –2.6 (s.d. 9.0) and ranged from –26 to 13. The variance was significantly different between the groups, so the Mann Whitney was used.

The difference between the means was significant ($U=480.5$, $N_1 = 37$, $N_2 = 37$, $p=0.027$). This supported the hypothesis stating that there would be differences in relative verbal and performance ability in women with adolescent idiopathic scoliosis compared to controls.

3.1.7.5.1 Full Scale I.Q.

Given this increased difference between verbal and performance I.Q. it was felt that it was important to ascertain whether there were any differences in I.Q. between the two groups, as the degree of difference between verbal I.Q. and performance I.Q. is positively correlated with Full Scale I.Q. (Matarazzo et al., 1985) .

One participant in the control group had a Full Scale I.Q. score greater than 3 s.d. from the mean and her data was therefore excluded from this analysis. Full Scale I.Q. scores on the WASI for participants without scoliosis averaged 114.43 (s.d.10.96), with a range of 88 – 131. Participants with scoliosis averaged 115.17;(s.d. 10.15), with a range of 93 -132. These scores were normally distributed in both groups.

Analysis using an independent measures t-test demonstrated that the difference between these means was not significant ($t(71) = -0.288$; $p=0.77$). This suggests that the difference between verbal and performance I.Q. observed above is not a function of differences in I.Q.

In order to assess whether the observed difference was a function of differences between the group in either verbal or performance I.Q., comparisons between the groups on these two variables were conducted.

3.1.7.5.2 Verbal I.Q.

Verbal I.Q. scores on the WAIS for participants without scoliosis averaged 111.89 (s.d.10.40), with a range of 81-129. The mean for participants with scoliosis was somewhat lower at 108.95 (s.d. 10.29), with a range of 88 - 125. These scores were normally distributed in both groups.

Analysis using an independent measures t- test demonstrated that these differences were not statistically significant ($t(72) = -1.225$, $p = 0.225$).

3.1.7.5.3 Performance I.Q.

Performance I.Q. scores on the WAIS for participants with scoliosis averaged 116.59;(s.d. 11.15), with a range of 98 - 139. Participants without scoliosis averaged 114.30 (s.d.11.31), with a range of 93-134. These scores were normally distributed in both groups. Analysis using an independent t-test demonstrated that the difference between these means was not significant ($t(72) = 0.880$, $p=0.382$).

Thus, although people with scoliosis had increased differences in between their verbal and performance I.Q. relative to controls, this did not seem to reflect significantly different scores for verbal or performance I.Q. when compared to controls.

3.1.8 Hypothesis testing: Whole group

As there were no differences between the scoliosis group and the control group on language lateralisation, verbal I.Q. and fluctuating asymmetry, the following hypotheses were testing using the data as a whole.

3.1.8.1 Hypothesis 6 – There will be a positive correlation between rightward physical directional asymmetry and leftward language lateralisation

In order to have a measure of total asymmetry, the indices a-b, b-c and c-d were summed for each participant. The resulting figures gave an indication of the direction of asymmetry in that a negative number indicated leftward asymmetry and a positive number indicated rightward asymmetry. A negative value of $Z\lambda^*$, the measure of language lateralisation indicated a left ear advantage and right hemisphere language, whereas positive values of $Z\lambda^*$ indicated a right ear advantage and left hemisphere language.

An association between rightward asymmetry and leftward lateralisation of language would therefore produce a positive correlation between z lambda * and the measure of total directional asymmetry, Total a-d.

The measure for total directional asymmetry for all participants was normally distributed. One participant had a score greater than 3 s.d. from the mean and their data was therefore excluded from this analysis. The data for z lambda *. was normally distributed and there were no outliers. The two variables were plotted against each other in a scattergram (See Figure 3-12).

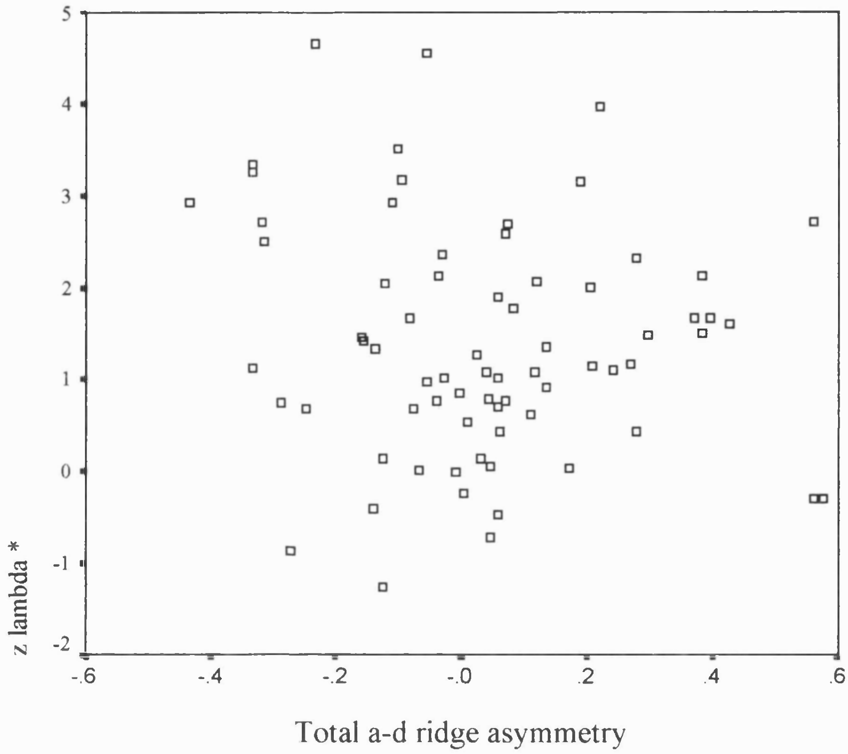


Figure 3-12 Scattergram of directional asymmetry and language lateralisation

Pearson correlation showed that there was no significant relationship between the total rightward directional asymmetry and leftward language lateralisation ($r=-0.13$; $p=0.27$). The hypothesis that there would be a correlation between rightward directional asymmetry and leftward language lateralisation was not supported.

3.1.8.2 Hypothesis 7 – There will be a negative correlation between fluctuating asymmetry and I.Q.

The measure for total fluctuating asymmetry for all participants was normally distributed. One participant had a score greater than 3 s.d. from the mean and their data was therefore excluded from this analysis. The data for I.Q. was normally distributed and there were no outliers. The two variables were plotted against each other in a scattergram (See Figure 3-13).

Pearson correlation showed that there was a significant inverse correlation between fluctuating asymmetry, as measured by the total absolute asymmetry of the interdigital areas and Full Scale I.Q. as measured by the WASI ($r= -0.272$; $p=0.02$) The hypothesis that there would be a negative correlation between fluctuating asymmetry and I.Q. was therefore supported.

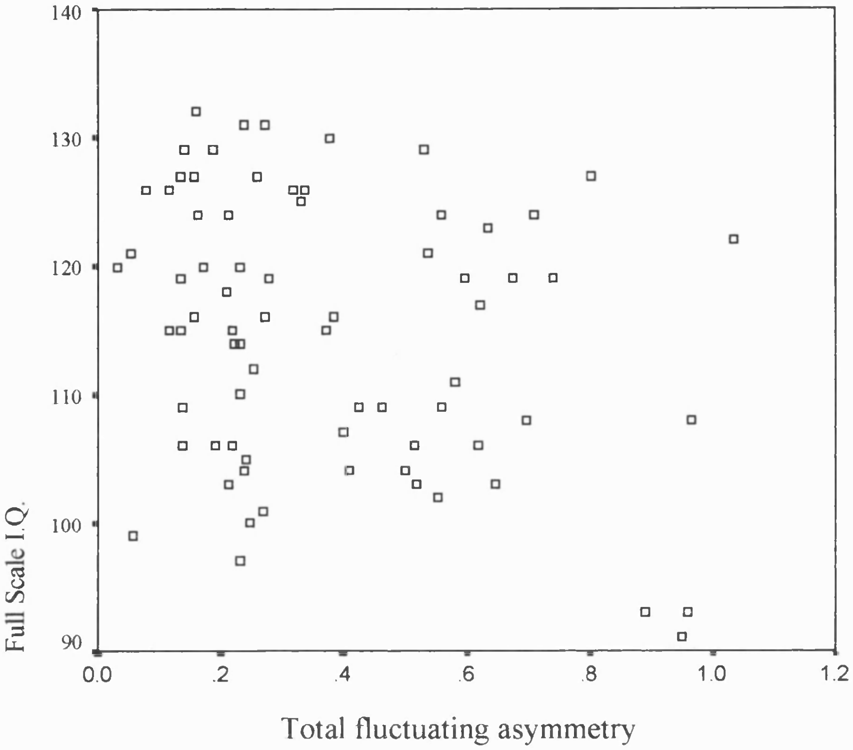


Figure 3-13 Scattergram of full scale I.Q. and fluctuating asymmetry

3.1.8.3 Hypothesis 8 – There will be a positive correlation between age of maturation and better performance skills relative to language skills.

The data for age of maturation for all participants was normally distributed. One participant had a score greater than 3 s.d. from the mean relative performance-verbal skills and their data was therefore excluded from this analysis. The data for performance-verbal was also normally distributed. The two variables were plotted against each other in a scattergram (See Figure 3-14).

Pearson correlation showed that there was a significant positive correlation between age of maturation, as measured by age at menarche and relative performance and verbal skill ($r=-0.388$; $p=0.001$) The hypothesis that later maturation would be associated with greater verbal-performance differences, with a bias in favour of performance skills, was therefore supported.

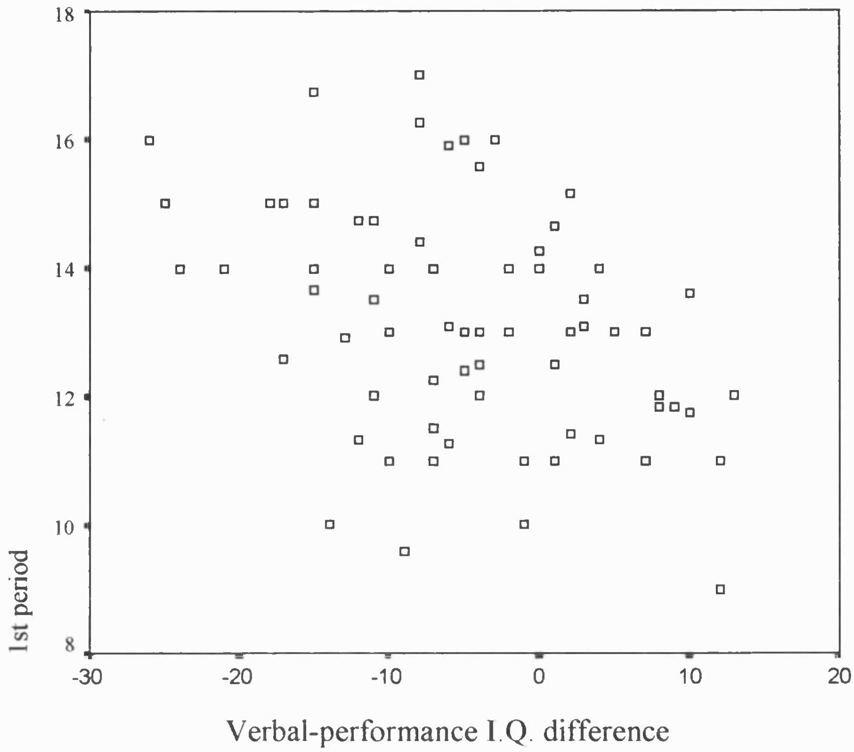


Figure 3 – 14 Scattergram of age of menarche and verbal-performance I.Q. difference

4 DISCUSSION

4.1.1 Hypothesis 1 – There will be differences in the lateralisation of language in women with adolescent idiopathic scoliosis relative to controls

There was no evidence in the current study to suggest that there were differences in the lateralisation of language in women with adolescent idiopathic scoliosis relative to controls. This finding contradicted those of both the previous studies in the field. Enslein and Chan (1987) found decreased lateralisation and Goldberg et al. (1995a) found increased lateralisation in adolescents with adolescent idiopathic scoliosis.

The most significant difference between the current study and the aforementioned studies is the age of the participants. Whilst their participants were adolescents, the average age in this study was 39.0 for people with scoliosis and 38.5 for controls. There is some evidence that lateralisation may decrease with age (Cabeza, 2001) so it is possible that older participants may demonstrate different degrees of language lateralisation compared with younger participants. However, one would expect this factor to act equally on participants with scoliosis and controls; the fact that there was no relative difference between people with scoliosis and controls on language lateralisation cannot therefore be easily explained in terms of age.

It is notable that the two previous studies were carried out with different nationalities; Enslein and Chan (1987) conducted their study with Americans, whilst Goldberg et al. (1995a) used Irish adolescents. Again, it is hard to see how this variable could account for the different findings. The only known difference between the two populations in terms of AIS seems to be that the estimates for the incidence of familal scoliosis in Ireland are lower than those for America (Goldberg, 2002, internet communication). As noted in Section 1.2.1.1, there is a dearth of reliable information about incidence of familal scoliosis, so it is hard to estimate the incidence in Britain.

About half of the participants in this study had a family history of at least one family member having scoliosis. Although about half the participants were recruited from a study examining genetics and scoliosis, in fact the proportion of participants from this source reporting a family history was the same as the proportion of participants from other sources reporting familal scoliosis (i.e. 0.5). It seems that the incidence of family history in this study was probably not therefore greatly affected by the inclusion of participants recruited from a genetic study. If this is the case, then this suggests a higher incidence of familial scoliosis in Britain than in either Ireland or America, if the estimates are to be believed. It is arguable that perhaps the mechanisms that lead to scoliosis in people with a family history of the disorder may be different to the processes that cause scoliosis in people without such a history. If this is the case, then one might well expect differences in lateralisation compared to studies with a putatively smaller number of familal scolioses. However, this hypothesis does not fit easily with the available data, since if Goldberg's estimates are correct, Goldberg et al. (1995a) would have had the lowest percentage of people with a family history (5%) and she found increased lateralisation of language, whereas Enslein and Chan (1987) would have had less incidence of familial scoliosis than the current study (25%) and found decreased lateralisation of language. The current study has the greatest incidence of lateralisation (50%) and yet finds no differences in lateralisation, rather than the anticipated greater decrease one would expect if this hypothesis were valid.

It is possible that nationality does make a difference, but only in terms of ability to perform the task appropriately. One could speculate that Irish and Americans might find it somehow easier to hear an auditory task read in an American accent, given that the American accent has much of its roots in Irish emigration. The accent used for the task used by Enslein and Chan (1987) is unknown, but since Goldberg et al. (1995a) used the same task as the current study it presumably had the same North American accent.

Although a previous British study (Pearce, unpublished) seemed to obtain similar results using the FWDT on British participants as had been found with Americans, a couple of subsequent studies have found, in common with the current study, much lower rates of significant language lateralisation when using the task with British participants (Swabey, unpublished; Smith, unpublished). Certainly the anecdotal reports of the participants in the current study would support the idea that British people find the North American accent difficult to understand in this context. Many people commented during the initial stereo and monotic practice trials that they were having difficulty hearing some words. As previously, though, this possible difference between the current study and previous ones does not easily account for the relative differences – or indeed lack of relative differences – between people with scoliosis and those without. That said, it is possible that problems with understanding the accent caused so much "noise" in the data that all differences were obscured.

There is one final possibility that may account for the disparity in findings. It is possible that there simply are no differences in lateralisation of language in scoliosis and that the findings of Enslein and Chan (1987) and Goldberg et al. (1995a) represent Type 1 errors. This possibility will be evaluated in the context of the findings regarding the other experimental hypotheses.

4.2 Hypothesis 2 – There will be an increase in directional asymmetry in women with adolescent idiopathic scoliosis relative to controls.

The findings from this study partially support the above hypothesis. Women with AIS in this study demonstrated increased directional asymmetry compared to controls only on the palmar area a_b, where they showed increased leftward asymmetry, relative to the leftward asymmetry generally seen in controls. This finding of increased directional asymmetry in the normative direction is consistent with the idea that women with AIS show a generalised increase in directional asymmetry. It does not seem to fit with the idea espoused by Goldberg et al. (1997) that the directional asymmetry follows a particular direction. Several studies (e.g. Dangerfield et al., 1997) have demonstrated increased directional asymmetry along a rightward gradient, and yet the dermatoglyphic results from both this study and indeed those of Goldberg et al. (1995b,1997) suggest increased directional asymmetry in the normative direction.

The directional asymmetry of palmar dermatoglyphics is often subsumed across both interdigital area and gender. It is commonly said that rightward directional asymmetry is the norm (e.g. Holt, 1968). However, if one examines the data for the individual palmar areas a_b, b_c and c_d, one finds that this is rather a generalisation and that a_b tends to exhibit leftward asymmetry. Thus the finding in the current study of increased leftward asymmetry on a_b reflects an increase in normal directional asymmetry, rather than reversed directional asymmetry. It is notable that many studies rely solely on a count of a_b to establish either directional and fluctuating asymmetry (e.g. Fananas et al. 1996). Given the inconsistency of directional asymmetry across the palm, this seems to be a short sighted approach as the result from one palmar area cannot distinguish between increased directional asymmetry in the normative direction and increased leftward asymmetry throughout the palmar measures.

Similarly, it is important to consider gender as a factor. The directional asymmetry of finger print ridges for example, has been shown to be strongly associated with the sex chromosome content (Jantz & Hunt, 1986). It seems that a similar effect may be found with palmar counts as Jantz and Brehme (1993) found that on average women had larger count on their left interdigital areas than on their right. The effect of this overall was to significantly increase directional asymmetry in the normative direction on both a_b and c_d, relative to men, so that women demonstrated increased leftward directional asymmetry on a_b and increased rightward asymmetry on c_d. The results of the current study are in line with such findings, in that women with AIS had increased directional asymmetry in the normative direction on a_b relative to other women.

It might be tempting to try to account for this in terms of differences in hormonal functioning, since, as noted in the introduction, there has been the suggestion that hormones may play a role in scoliosis, specifically increases in growth hormone and testosterone (Skogland & Miller, 1980). However, increased directional asymmetry in one area of the palm is not a sufficient basis on which to speculate.

Reviewing the findings from the two papers written by Goldberg et al. (1995b; 1997) regarding dermatoglyphic measures and AIS, it seems that, like language lateralisation, the results in this field are limited and inconsistent. In the first paper Goldberg et al. (1995b) found significantly reversed directional asymmetry on all palmar dermatoglyphics, so that when controls were rightward, on atd angle, a_b and b_c, people with scoliosis were leftward and when controls were leftward on c_d, people with scoliosis were rightward.

However, in the second paper (Goldberg et al., 1997) there were no significant increases in directional asymmetry on any interdigital measures, although there was significant leftward asymmetry on the atd angle. Goldberg did not comment on the apparent disparity between these results and those of the previous study, which were perhaps all the more notable given that the 1997 study had twice the number of participants (164) than the original research (78).

The findings of the current study are actually more consistent with those of Goldberg et al.'s later study, in that this study also only found one area with increased leftward asymmetry. Given the inconsistency of the overall profile of results from the studies in this area, it would seem inappropriate to draw any firm conclusions from the current data.

As noted in Section 3.1.7.2.4, although there were few differences in directional asymmetry between AIS and Controls, there were significant differences in total ridge count, with women with AIS having a greater total ridge count than women without. It is thought that this may relate to rate of maturation (Meier, Goodson & Roche, 1987) and so the significance of this finding is discussed below alongside age of menarche in Section 4.4.

4.3 Hypothesis 3 – There will be an increase in fluctuating asymmetry in women with adolescent idiopathic scoliosis relative to controls.

This hypothesis was not supported by the results from the study which indicated that there were no differences between people with scoliosis and controls in terms of fluctuating asymmetry. This is somewhat surprising in that it seemed that the observation of increased incidence of non-spinal asymmetry in AIS (e.g. Pecina et al., 1991) would be strongly suggestive of increased developmental instability, if not directional asymmetry.

Unlike Goldberg's previous studies (1995b; 1997), the current study used a summed measure of fluctuating asymmetry. In the 1997 paper, Goldberg et al. only found evidence of fluctuating asymmetry on the a_b measure, so it is possible that if the interdigital area in this study had been analysed individually, a similar finding would have emerged. However, the measure of total fluctuating asymmetry was specifically used because it was noted as being a more reliable measure than separate measures (Pechenkina et al., 2000).

Many studies in the field of anthropometry use a summed measure which consists of a large number of traits. (e.g. Burwell, Dangerfield, James, Johnson, Webb, & Wilson, 1984). Given the varied results to date, It seems likely that this approach might be more effective in delivering reliable estimations of both fluctuating and directional asymmetry in this context.

Rosa et al. (2000) concluded that the results of their study suggested that it might be easier to detect the effect of fluctuating asymmetry than that of atypical lateralisation. They speculated that this might be because dermatoglyphics develop in a very limited period and are then fixed for life, whereas functional lateralisation is affected by many other post-natal biological, cultural and situational factors. It is therefore all the more surprising that the current study found little evidence of differences on either variable.

However, the lack of differences in both fluctuating asymmetry and language lateralisation may be significant. Developmental instability has been shown to increase the incidence of anomalous lateralisation, deviating from the mean in either direction (Yeo et. al, 1997). Language lateralisation in people with AIS in the studies of both Goldberg et al. (1995a) and Enslein and Chan (1987) deviated from the mean, in that it was above and below the expected mean of controls in both cases. It is not known whether their samples also demonstrated developmental instability, but Goldberg et al. (1995b. 1997) have demonstrated developmental instability in the same clinic population, if not the same cohort.

In the current study, for whatever reason, no significant increase in fluctuating asymmetry was seen relative to the control group. Similarly, there was no difference in language lateralisation. Clearly, a null result is limited in its implications, but this result is consistent with the hypothesis that developmental instability may be the factor that accounts for the observed differences in the literature.

4.4 Hypothesis 4 - There will be differences in age of maturation in women with adolescent idiopathic scoliosis relative to controls.

Results from this study would suggest that the women with AIS experienced somewhat later maturation, the mean age of menarche in AIS being 13.45 and the mean age of menarche in controls being 12.87. However, this difference was not significant (p=0.17).

One factor that may have contributed to this lack of significance may have been that some participants has difficulty in remembering the exact month that their first menustruation occurred. Although self-report of menarche has been used previously (Newcombe et al., 1989), this was with undergraduate participants, who would arguably be closer to puberty than the present sample and therefore presumably find it easier to remember.

However, the significant relationship between age of maturation and better relative performance than verbal skills (See Section 4.4 below) suggests that the data is not invalid, just not sufficiently accurate to detect the difference between women with

AIS and controls. Given that previous studies have found differences in first menstruation in terms of a few months (e.g. Goldberg, Dowling & Fogarty, 1993), this seems quite plausible.

Of course, it may also be the case that there is genuinely no difference between the two groups in terms of age of maturation, but the results from the measures of both total palmar ridge count and Performance – Verbal differences (See Section 4.5.4) would be consistent with an increased age of maturation in the AIS group.

4.4.1 Total ridge count and age of maturation

Women with AIS had a significantly greater number of ridges on their palms compared to women without AIS. This is a finding that may be of relevance to the hypotheses under examination since there is evidence to suggest that ridge count may be related to rate of maturation. Meier, Goodson and Roche (1987) compared finger ridge count and palmar patterns in early and late maturing males and females. They discovered that late maturing males exhibiting larger total finger ridge counts and late maturing females exhibited more complex palmar patterns. Unfortunately, Meier et al. did not assess total palmar ridge count, but it seems that their general finding that delayed growth produces greater complexity in palmar patterns would suggest that later maturers would indeed have a greater number of palmar ridges.

This has two implications. Firstly, Meier et al. make the point that if dermatoglyphic patterns are associated with pubertal timing, then it seems that individuals "tend to remain on a relatively constant tempo of growth that was set down early in prenatal life." (Meier et al., p. 369). This would suggest, as noted in Section 1.7.3.1, that many of the findings concerning pubertal timing and cognitive ability may actually reflect the impact of in utero rate of development. As noted in Section 1.7.3, it seems that the two hemispheres of the brain exhibit different rates of growth in utero at different points in time (e.g. Geschwind & Galaburda, 1985) and it has been argued that changes in this growth pattern can therefore produce unusual asymmetries and, arguably, differences in ability (Mittwoch, 1978)

Secondly, it may suggest that the AIS cohort in the current study were indeed later maturers, even though this was not detected by the age of menarche data. This possibility might explain the finding of increased relative performance ability in women with AIS.

4.5 Hypothesis 5 – There will be differences in relative verbal and performance ability in women with adolescent idiopathic scoliosis relative to controls.

This study found that women with AIS demonstrated significantly better performance skills relative to their verbal skills compared to women without scoliosis. There were no significant differences in terms of verbal or performance I.Q. compared to controls, but this may reflect the fact that the VIQ-PIQ measure was within subjects and therefore had more power to detect any differences.

4.5.1 Significance of verbal-performance differences

For women between the ages of 35 – 44, a difference of 7.51 between verbal and performance scores is statistically significant at the 0.05 level (Psychological Corporation, 1999). The mean difference between performance and verbal scores was –7.51 for women with AIS so this score is statistically significant. However, this does not suggest that it is clinically significant, just that it is unlikely to have occurred by chance.

The clinical significance can be assessed by discovering how common such differences are in the general population. The WASI manual suggests that such a difference is found in about 30% of people in the ability level 110-119 (full scale I.Q.). Unfortunately, although they give separate estimates for children, they do not give separate estimates by gender and it could be argued that the finding of better performance skills than verbal skills in a female population is more unusual, in that women are often believed to be better at verbal rather than performance skills (e.g. Kimura, 1999).

The finding of a 7 point difference however, is clearly unlikely to make any significant difference in terms of an individual's functioning or their profile on neuropsychological testing.

4.5.2 Issues in the interpretation of Verbal-Performance Differences

The verbal and performance subscales of the Wechsler Adult Intelligence Scales have long been associated with the functioning of left and right cerebral hemispheres, respectively (e.g. Reitan, 1955). The rationale behind this association is that Wechsler verbal scores obviously rely to a great extent on verbal ability whilst performance scores are more dependent on visuospatial skills and these abilities are seen as being generally lateralised to the left and right hemisphere, respectively.

Verbal and Performance differences are therefore often interpreted as reflecting the relative functioning of the two hemispheres. However, the validity of this distinction has been the subject of debate, with some authors maintaining that Verbal and Performance I.Q. discrepancies are of little consequence (Lezak, 1983) and others believing that they are a useful indication of hemispheric function (e.g. Matarazzo & Herman, 1985). There are certainly several important issues to consider before interpreting verbal and performance scores in this light.

Firstly, in interpreting Verbal and Performance discrepancies it is important to consider the fact that the Verbal and Performance subscales tap into a number of different abilities and these consituent skills may not necessarily be lateralised to the same hemisphere, or indeed may not be lateralised at all.

Most of the literature examining Verbal – Performance differences discusses the older version of the Wechsler Intelligence Scales, the WAIS-R. In this test, verbal I.Q. is derived from the scores on Information, Comprehension, Arithmetic, Similarities, Digit Span and Vocabulary. Performance I.Q. is obtained from scores on Digit

Symbol, Picture Completion, Block Design, Picture Arrangement and Object Assembly.

With Verbal and Performance I.Q. derived from so many different tests, it is not surprising that a number of different abilities may be being measured. For example, whilst Picture Completion and Picture Arrangement are deemed to be performance tests, they also tap into verbal ability to some extent (Lezak, 1995) and so, in the majority of the population, may not be a particularly pure measure of right hemisphere function.

One of the most notable differences between verbal and performance task demands is that four out of the five performance tasks are timed, whereas scores in only one of the six verbal tasks are contingent on response speed. Speed of processing is not believed to be lateralised to either hemisphere (e.g. Hodges, 1998), but it seems that it is a variable that may well differentially affect performance and verbal I.Q. (e.g. Skilbeck, 1996).

The idea that the Wechsler scales may not neatly parse into two coherent factors has been borne out by factor analysis of both the WAIS-R and its predecessor, the WAIS. Three factors have consistently emerged: Verbal Comprehension, Perceptual Organisation and Memory/Freedom from distractibility (e.g. Atkinson et al., 1989, Kaufman, 1990, Leckliter, Matarazzo & Silverstein, 1986).

The progenitors of the most recent version of the WAIS, the WAIS-III (The Psychological Corporation, 1997) have taken account of such findings by devising a four factor structure to the test that has been borne out by subsequent factor analysis studies. In the WAIS-III Verbal tests, Vocabulary, Similarities and Information constitute the Verbal Comprehension Index and Arithmetic, Digit Span and Letter-Number Sequencing form the Working Memory Index. With Performance tests, Picture Completion, Block Design and Matrix Reasoning cluster together as the Perceptual Organisation Index and Digit Symbol Coding and Symbol Search consitute the Processing Speed Index. It has been suggested that the “purer” Verbal Comprehension Index and Perceptual Organisation Index of the WAIS III may give a better picture of an individual’s verbal and non-verbal ability, and therefore implied left and right hemisphere processing skills than differences between Verbal and Performance I.Q. (Kaufman & Lichtenberger, 1999).

Of course, the current study utilised the abbreviated scale and so this was not a possibility. However, it is notable that Verbal I.Q. on the WASI is derived from 2 out of the 3 tasks of the WAIS-III Verbal Comprehension Index, namely Vocabulary and Similiarities. Similarly, WASI Performance I.Q. is calculated using scores on Block Design and Matrix Reasoning, 2 of the 3 tasks of the WAIS-III Perceptual Organisation Index. Furthermore, although the difference between Verbal and Performance tasks in terms of timing is still present on the WASI, it is arguably less dramatic in that whilst neither of the verbal tasks are timed, only one of the two performance tasks (Block Design) is time-dependent. It seems likely therefore that

Verbal and Performance I.Q. discrepancies on the WASI may be somewhat less subject to the criticisms of discrepancies of WAIS and WAIS-R Verbal and Performance I.Q. However, there are still some more general factors to consider when interpreting such scores.

Another issue in associating verbal I.Q. scores with left hemisphere function is that even if one believes Verbal I.Q. to tap solely into verbal ability, verbal ability is unlikely to be the exclusive domain of the left hemisphere, even in people in which that hemisphere is language dominant (e.g. Segalowitz, 1983). Indeed, it seems that the right hemisphere plays a prime role in the comprehension of the emotional aspects of language (e.g. Hodges, 1998). Moreover, when the left hemisphere has been removed or severely damaged in childhood, the verbal capacities of the right hemisphere may develop to such an extent to appear relatively normal (e.g. Smith & Sugar, 1975). Even without such damage, the right hemispheres of left handed individuals appear to have greater verbal ability than those of right handers (e.g. Henninger, 1992). That said, it is generally acknowledged that in right handed individuals with an intact left hemisphere that is dominant for language, the language abilities of the right hemisphere are at best rudimentary (e.g. Bogen, 1985). As Churchland (1986, p. 197) has commented, if by "lateralisation" one means that the "left hemisphere in many brains performs better than the right hemisphere on language tasks, then yes, language is lateralised to the left hemisphere. If it implies that the right hemisphere has no capacity for language, then the claim is still sub judice."

A further point to consider is that even in tasks which are generally lateralised, the strength of lateralisation is not necessarily equal. For example, in right handers, visuospatial functions are not as strongly lateralised to the right hemisphere as language functions are lateralised to the left hemisphere (Bryden & MacDonald, 1987). In left handers, visuospatial ability is even less lateralised and is equally likely to be represented to the left, right or bilaterally (Bryden et al, 1983).

As noted, handedness can potentially affect the validity of interpretations of Verbal - Performance differences that invoke lateralisation, but it is not the only variable to do so. Gender may also be a factor as it seems that women may exhibit less functional asymmetry than males (e.g. Crawford, 1992). Obviously in the current study the impact of these variables was kept constant in that all participants were right handed females.

It can be seen that there are several factors that can affect the interpretation of Verbal – Performance differences in general population. One factor that has not hitherto been mentioned, and that may be particularly relevant for people with scoliosis, is that of the posited differential effect of education on Verbal and Performance skill.

4.5.3 Possible impact of scoliosis on education

One explanation of the finding of increased Verbal – Performance differences in people with scoliosis is simply that scoliosis has a significantly deleterious effect on education and that education tends to affect Verbal I.Q. more than Performance I.Q. (e.g. Reitan, 1996). This seems unlikely because there is no evidence in the literature to suggest such a problem with education in scoliosis. However, the lack of research does not necessarily mean that the problem does not exist.

Hypothetically, education could be disrupted in people with scoliosis through time off for treatment or possibly through negative experiences at school as a consequence of the person's appearance. In the current study, it seems unlikely that time off for treatment would be a significant variable since only a third (13) of participants had been treated whilst at school, half wearing a brace and half receiving spinal fusion, the remaining one individual receiving both treatments consecutively. Currently spinal fusion requires only about three weeks off school (e.g. Vanderbilt, 2002) and even in the past, the maximum stay in hospital was only for several weeks (Fonda, 2002). Bracing requires regular visits to the hospital, but these total only 3 or 4 days a year, which is unlikely to be significant (Scoliosis Association U.K., personal communication). Although the possibility of negative experiences at school cannot be ruled out, there is no evidence in either the academic literature or from self help groups such as SAUK that this is a significant issue for people with scoliosis.

It seems likely therefore that the increased performance scores reflect some innate difference in women with AIS.

4.5.4 Maturation and Verbal-Performance differences.

The finding of better performance than verbal skills fits with studies suggesting that later maturing children perform better on spatial tasks (Waber, 1979). Obviously, the difference in maturation rates was not significant in this sample, but, for the reasons outlined above, it is possible that this data was not sufficiently reliable to detect differences in maturation between the two groups.

The possibility that rate of pubertal maturation mirrors in utero growth (Meier et al, 1987) may also fit the profile of the current results, given that it has been suggested that prenatal growth rate may predict not only right hemispheric specialisation, but also associated cognitive abilities (e.g. Netley, 1988), with delayed growth being associated with poorer verbal function relative to performance. In this study women with AIS had a greater total palmar ridge count, which may indicate slower in utero growth and therefore fit with the finding of better performance skills relative to verbal skills.

4.6 Hypothesis 6 - There will be a positive correlation between rightward physical directional asymmetry and leftward language lateralisation

This study found no evidence for a relationship between rightward asymmetry and leftward language lateralisation in people with scoliosis and controls. Given the apparently inconsistent nature of palmar directional asymmetry, this was not particularly surprising. The evidence of a reliable link between directional asymmetry and lateralisation is also rather tenuous.

4.7 Hypothesis 7 – There will be a negative correlation between fluctuating asymmetry and I.Q.

The current study found a negative relationship between fluctuating asymmetry and I..Q. in women with AIS and controls. There only appears to be only one paper published on this topic (Furlow et al, 1997) which demonstrated a similar negative correlation. Clearly the current study supports this finding, although it is worth noting that whilst the correlation is significant, it is not particularly strong ($r= -0.272$).

4.8 Hypothesis 8 – There will be a positive correlation between age of menarche and better performance skills relative to language skills.

Again, results from the study supported this hypothesis. This would be consistent with Waber's (1976) findings of later maturation facilitating performance skills. It would also contradict studies with adults that have found no such relationship and concluded that it only held for individuals who were still developing (Strauss & Kinsbourne ,1981).

Given the increasingly early age of maturation, the idea that rate of maturation at puberty affects spatial skills may have implications for the skills profile of the younger generation. Alternatively, if Meier et al.(1987) are correct in believing that rate of maturation at puberty is more of a marker for rate of maturation in utero, one would expect increases in early pubertal maturation to have no impact on cognitive profile.

4.9 Validity of null findings

The validity of the current findings should be considered in the context of sample size – this study having a larger sample size than both of the published papers on the topic. Goldberg et al. (1995a) tested 31 adolescents with AIS and 20 controls, whereas Enslein and Chan (1987) tested only 18 children with AIS and 13 controls, and the current study tested 37 women with AIS and 37 controls.

This study also used the same dichotic listening task as Goldberg et al., as well as the same dermatoglyphic measures used in her other 1995 study on developmental instability in AIS.

However, the results did not support either Goldberg et al. (1995b) or Enslein and Chan (1987). The methodological possible reasons for this have been discussed above, but given that the study replicated several other findings outside the realm of scoliosis, it seems possible that in the particular population sampled by this study, women with AIS genuinely did not have increased developmental instability or differences in language lateralisation.

As noted, it is possible that the apparent increased incidence of a familial history of scoliosis might account for such differences. Familial scoliosis may be more likely to be caused by other causes of scoliosis such as collagen abnormalities, rather than the postulated developmental instability. That said, developmental instability itself has a heritable component, so one could make the converse argument.

4.10 Limitations of the current study

As acknowledged in the Results Section, the decision was taken not to use the Bonferroni correction for multiple testing. The nature of the data necessitated the use of multiple tests, but it was felt that the risk of missing an effect was more problematic than that of apparently finding an effect that was not present, so the study erred on the side of Type I rather than Type II error. It is all the more notable, therefore, that the effects one would predict from the literature concerning scoliosis and developmental instability did not appear.

Another statistical caveat to be made, is that some of the relationships were correlational, not causal. Clearly, it is inappropriate to infer causality from these correlational relationships. For example, although there appears to be an inverse correlation between fluctuating asymmetry and I.Q. in this study, one cannot conclude that increases in fluctuating asymmetry *cause* decreases in I.Q. This point is particularly relevant when considering the data on age of maturation and cognitive ability. Although Saugstad (1979) has proposed a theory that would account for differences in cognition as a function of later maturation, other authors in this field do not appear to have done so (Waber, 1976). It is possible that late maturation at puberty may be correlated with particular cognitive profiles not because later puberty causes them, but because late puberty is associated with slower development in utero (Meier et al., 1987) which may affect later cognitive profile.

A factor is this study that is perhaps both a strength and a weakness is the use of a matched pair design. Participants were matched on age, years of education and occupational category. They were also all female and right handed. Thus the impact of AIS and directional asymmetry and fluctuating asymmetry on cognitive ability and handedness could not easily be assessed. Obviously any interaction with gender on any variables was also impossible. That said, this study was unusual in the AIS field in using adult women, rather than adolescents and having a good age range of participants.

As noted, the Fused Word Dichotic Task does not seem to be as effective in British people as in North Americans (e.g. Swabey, unpublished). Thus it is more difficult to interpret the null results of this study with regard to language lateralisation.

Another potential methodological weakness of this study is that scoliosis status and age of menarche were self reported.. Although this approach has been used in other studies (E.g. Bryden, 1989. it would have been preferable to have had more concrete data.

It would also have been useful to have data on the direction of participants curvature so that stronger conclusions could be drawn about the consistency of any directional bias in asymmetry.

4.11 Clinical Implications

It always difficult interpreting null findings, but much of the clinical relevance of this study, as far as people with scoliosis are concerned, stems from what it did not find, as much as what it did find.

As noted in the introduction, the factors examined in this study have many potential clinical implications. If people with scoliosis were to have decreased lateralisation of language, as suggested by Enslein and Chan (1987), this would be associated with an increased incidence of dyslexia (e.g. Bloch & Zaidel, 1996) and schizophrenia (Saugstad, 1998). It also might explain the "academic malachievement " observed by Herman et al. (1985). Conversely, support for the finding of Goldberg et al. (1995a) of increased lateralisation might lend weight to the idea that people with scoliosis have rightward physical asymmetry and leftward cerebral asymmetry. As noted in the introduction, increased lateralisation of function might render people with scoliosis more susceptible to the effects of lateralised brain damage. If this were the case, it would be useful to be aware of this fact when planning neurorehabilitation for someone with scoliosis.

Similarly if people with scoliosis were conclusively found to mature earlier or later, the research reviewed in the Introduction would lead one to anticipate different cognitive profiles (e.g. Waber, 1979) and possibly a different incidence of schizophrenia and bipolar disorder (Saugstad, 1998). .A finding of increased rightward directional asymmetry might suggest that people with scoliosis would be particularly good at spatial tasks (e.g. Kimura, 1994) and the link between fluctuating asymmetry and I.Q. found by Furlow et al. (1997) would suggest that increased fluctuating asymmetry would imply reduced intelligence in people with AIS. If this study were to have evidence of decreased ability on the WASI, this would have had implications for the clinical care of people with scoliosis, whether in physical health or mental health settings.

Given the 2-3% incidence of scoliosis (Lonstein, 1988), these implications are potentially significant. In fact, the current study found no evidence for any difference between controls and people with scoliosis on measures of fluctuating asymmetry, language lateralisation and age of maturation. This would suggest that all the above possible clinical ramifications do not apply to people with AIS.

The only differences between the two groups were in terms of increased directional asymmetry on the palmar index a_b, increased total ridge count and increased verbal-performance differences (with increased performance ability relative to verbal ability). It is hard to assess the significance of the former finding. It could be taken as evidence that supports the finding of Goldberg et al. (1995b) regarding increased directional asymmetry, but as noted above, it seems like a rather tenuous basis for such a conclusion.

The serendiptous finding of increased total ridge count may as noted suggest that women with AIS have delayed development in utero compared to women with controls. This might have implications for the relative development of their verbal/performance skills (Netley, 1988), although results from this study would suggest that any impact is unlikely to be dramatic.

In general, the study would underline the importance of applying a biopsychosocial model to clinical practice, in that even apparently purely physical conditions such as adolescent idiopathic scoliosis may have underlying biological factors that may impinge on psychological aspects of the individual's functioning.

This point is emphasised by the study's findings concerning the general population. Analyses using data from both women with and without AIS suggested that increasing fluctuating asymmetry (i.e. developmental instability) is associated with decreasing I.Q. and also that later maturation at puberty is associated with better performance skills, relative to verbal skills.

4.12 Future research

There are always possibilities for improving research and it seems that there are a number of ways in which the ideal version of the current study could be achieved.

Firstly, it would be better to use cohort of women with and without scoliosis whose age of menarche had been accurately recorded, as it seems that it is not always easy to recall such information. Secondly, although every attempt was made in the current study for the sample to be as representative as possible, it does seem likely that people who are willing to volunteer for a study may not represent the general population. This point is illustrated by the above average I.Q. of both controls and women with AIS. It would therefore be informative to use a consecutive series of women with adolescent idiopathic scoliosis – for example a sample of all women attending for treatment. Given that adult women with scoliosis are unlikely to present for treatment unless experiencing significant difficulties, to be representative any clinic sample would have to consist of either older adolescents or young people who were still contactable via a clinic, but had finished development. Such a sample would enable one to assess the extent of directional asymmetry, fluctuating asymmetry, lateralisation, cognitive ability and indeed academic performance in a more representative sample of people with AIS than perhaps with people who had more proactively volunteered. As a control condition, one might use a consecutive sample of people attending an orthopaedic clinic for other orthopaedic conditions. A clinic sample would also solve the problem of insufficient information regarding curve convexity.

As mentioned above, it is possible that a series of anthropometric measures would be an alternative way to assess fluctuating and directional asymmetry. Furthermore, the suggestion has been made that that such measures would correlate more strongly with cognitive asymmetries (Yeo et al., 1997). The use of both dermatoglyphic and anthropometric measures would allow one to test this hypothesis. The use of multiple measures would also allow the consistency of any directional asymmetry to be assessed more accurately.

The Fused Word Dichotic Task is another methodological problem that could be rectified. It seems that the Fused Word Dichotic Task may be affected by the difference in accent, so a British version of the task might be more appropriate. A computer based reaction time measure of response might also be a more sensitive way of assessing differences in language lateralisation.

Overall the findings of a connection between fluctuating asymmetry, age of maturation and cognitive ability would suggest that it would be worth examining any condition that is associated with an increase in developmental instability or difference in rate of maturation to see if it is also asssociated with differences in cognitive ability.

4.13 Conclusion

The findings of the current study are illustrated in Figure 4-1. As can be seen, the study demonstrated that women with AIS tend to be better at performance tasks relative to verbal tasks compared to women without scoliosis. There was also some evidence to suggest that women with AIS may have increased directional asymmetry. There was no evidence to support the hypothesis that women with AIS would demonstrate increased developmental instability and differences in language lateralisation relative to controls. Although there were no significant differences in age of menarche between people with AIS and controls, there was indirect evidence in the form of increased total palmar ridge counts to suggest that women with AIS in this sample may have matured later than women without AIS. This possibility was thought to maybe explain the differences between verbal and performance I.Q. observed in women with AIS.

The most parsimonious explanation for the mixed findings concerning language lateralisation in AIS seems to be that increased developmental instability, rather than directional asymmetry, as suggested by Goldberg et al. (e.g. 1995b) may lead to anomalous language lateralisation, be that increased or decreased. AIS participants in the current study did not seem to have significantly increased developmental instability and therefore did not have differences in lateralisation.

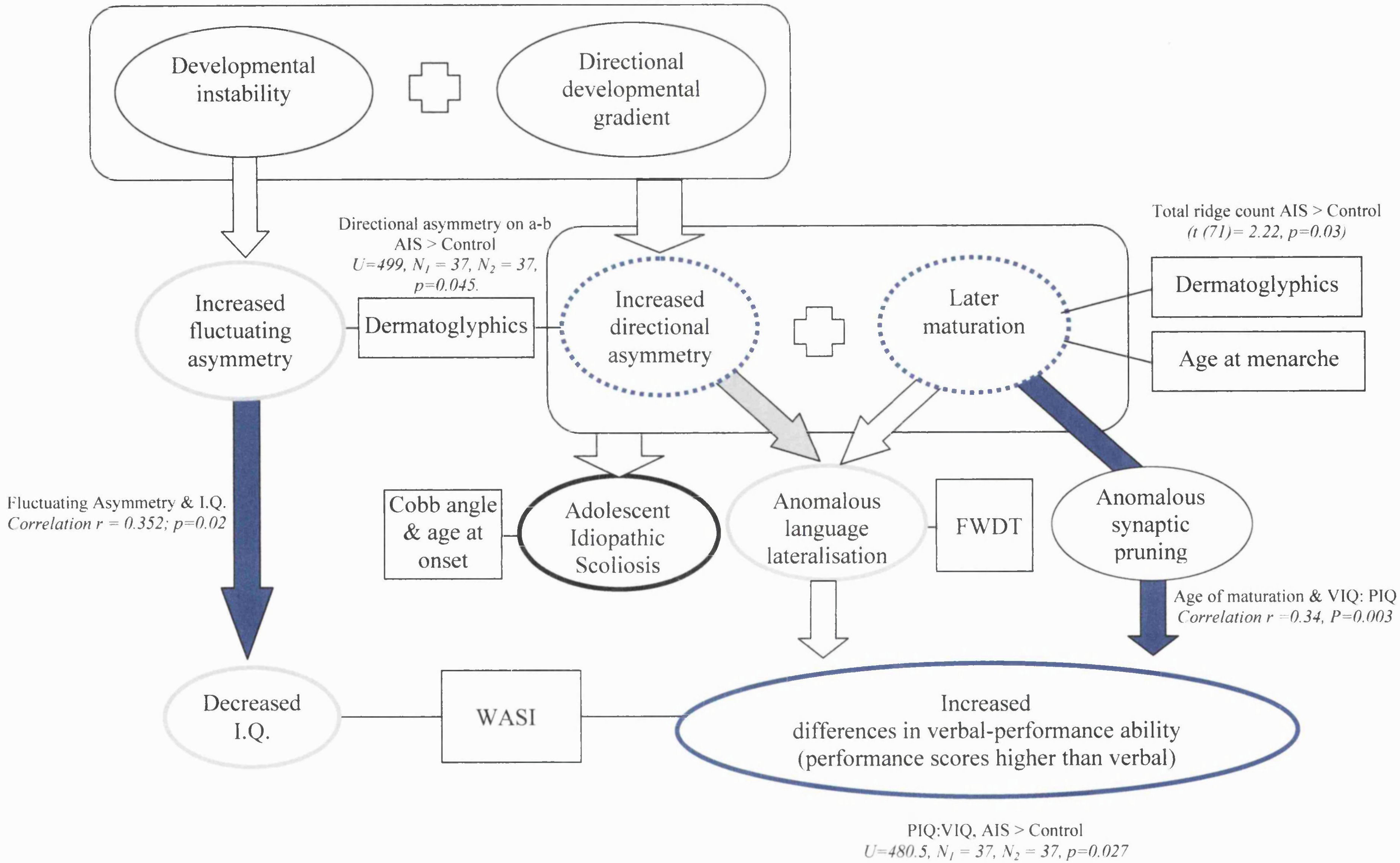


Figure 4-1 Diagram illustrating findings of current study

Key to Figure 4-1

Measure

Construct - untested

Construct – No significant differences found between AIS and Control

Construct – Significant differences found between AIS and Control

Construct – Some evidence of differences between AIS and Control (See text for details)

Postulated relationship between variables - untested

Postulated relationship between variables – No significant correlation between variables found

Postulated relationship between variables – Significant correlation between variables found

When considering the inconsistent nature of findings in this field, it is worth noting Sevastik's (1998) comment that idiopathic scoliosis in general is a polymorphic disorder, consisting of an collection of pathologic conditions which have nothing in common save a thoracospinal deformity and an unknown aetiology. He advocated the development of a more specific taxonomy as a crucial prerequisite for productive research in scoliosis. Given the heterogeneity of findings in the current area, such an idea seems eminently sensible.

The results of this study also support findings suggesting that rate of maturation and developmental instability may affect cognitive ability. Such results underline the importance of taking a biopsychosocial approach to clinical psychology.

5 Appendices

Appendix 1 - Study Information Sheet for people with scoliosis

Confidential

Study information sheet for volunteers with scoliosis

Neuropsychological Correlates of Adolescent Idiopathic Scoliosis

Researchers:

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We are asking for your help in our research proposal. As you may know, adolescent idiopathic scoliosis (AIS) is a curvature of the spine that starts in adolescence for no apparent reason. There are a number of theories concerning the causes of AIS. One idea is that people with AIS are simply more likely to develop in a generally more asymmetrical fashion – this is called increased "developmental instability". It is also possible that increased developmental instability may be more likely to lead to AIS when someone also reaches puberty early. One implication of these ideas is that people with AIS may not only have increased spinal asymmetry, but may also have increased asymmetry in their brains.

The brain is divided into two parts, or "hemispheres". In most people, the two hemispheres tend to control different functions. For example, language is usually largely controlled by the left hemisphere and visuospatial and emotional processing are usually associated with the right hemisphere. This asymmetrical control of different functions is called "lateralisation"

There has been very little research with AIS in this area, but one previous study has found that people with AIS are more lateralised for language than other people (i.e. one side of the brain has even greater control over language than is usually the case). It has been suggested that such increased lateralisation of language may lead to differences in language ability, but this idea has never been tested in people with AIS.

This study has several goals. Most importantly, it aims to find out whether people with AIS do indeed have increased lateralisation of language and whether they have different language skills than people without AIS. Information will also be collected about developmental instability and onset of puberty, so that it should be possible to determine whether any increased lateralisation is associated with increased developmental instability and/or early maturation.

Results from this study will not only give information about the organisation of the brain in people with AIS, but will also contribute to our understanding of what causes AIS. In addition, the results from people without scoliosis will illuminate the relationship between developmental instability, age of maturation and cognitive ability in people without scoliosis.

The study will involve a number of tasks. Although time taken to complete these tasks will vary, we estimate that they should not take longer than an hour and a half in total. Firstly, people who participate will be asked to fill in two brief questionnaires. They will then be asked to do a "dichotic listening task". In this task, someone listens to a number of different words over headphones and have to indicate what word they have heard. After this task is completed, there will then be a number of different verbal and non-verbal tasks to complete. Finally, a palm print of the participant's hands will be taken – this will allow us to measure developmental instability by counting the number of lines on each palm print.

Obviously, in order to do this study, we need to involve people with adolescent idiopathic scoliosis. However, we also need people who do not have idiopathic scoliosis so that we have a comparison group. Gender and handedness are known to affect lateralisation, so in order to avoid this complication, we would like all our participants to be right handed women. Similarly, familiarity with English may affect language ability, so we need all our participants to speak English as a first language.

You do not have to take part in this study if you do not want to. If you decide to take part you may withdraw at any time without having to give a reason. All the information you give us is confidential. It will be kept separately from your name and referred to only by a code number.

All proposals for research using human subjects are reviewed by an ethics committee before they can proceed. This proposal was reviewed by the Joint UCL/UCLH Committees on the Ethics of Human Research.

If you have any questions about this study, please contact Tania Thorn on 07967 596 056 or by e-mail at tania.thorn@aol.com

Appendix 2 - Study Information Sheet for people with scoliosis

Confidential

Study information sheet for volunteers with scoliosis

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There has been very little research with AIS in this area, but one previous study has found that people with AIS are more lateralised for language than other people (i.e. one side of the brain has even greater control over language than is usually the case). It has been suggested that such increased lateralisation of language may lead to differences in language ability, but this idea has never been tested in people with AIS.

This study has several goals. Most importantly, it aims to find out whether people with AIS do indeed have increased lateralisation of language and whether they have different language skills than people without AIS. Information will also be collected about developmental instability and onset of puberty, so that it should be possible to determine whether any increased lateralisation is associated with increased developmental instability and/or early maturation.

Results from this study will not only give information about the organisation of the brain in people with AIS, but will also contribute to our understanding of what causes AIS. In addition, the results from people without scoliosis will illuminate the relationship between developmental instability, age of maturation and cognitive ability in people without scoliosis.

The study will involve a number of tasks. Although time taken to complete these tasks will vary, we estimate that they should not take longer than an hour and a half in total. Firstly, people who participate will be asked to fill in two brief questionnaires. They will then be asked to do a "dichotic listening task". In this task, someone listens to a number of different words over headphones and have to indicate what word they have heard. After this task is completed, there will then be a number of different verbal and non-verbal tasks to complete. Finally, a palm print of the participant's hands will be taken – this will allow us to measure developmental instability by counting the number of lines on each palm print.

Obviously, in order to do this study, we need to involve people with adolescent idiopathic scoliosis. However, we also need people who do not have idiopathic scoliosis so that we have a comparison group. Gender and handedness are known to affect lateralisation, so in order to avoid this complication, we would like all our participants to be right handed women. Similarly, familiarity with English may affect language ability, so we need all our participants to speak English as a first language.

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All proposals for research using human subjects are reviewed by an ethics committee before they can proceed. This proposal was reviewed by the Joint UCL/UCLH Committees on the Ethics of Human Research.

If you have any questions about this study, please contact Tania Thorn on 07967 596 056 or by e-mail at tania.thorn@aol.com

Appendix 3-Questionnaire for Control Participants

Participant______

Questionnaire

1. What is your date of birth?
2. What is your occupation?
3. What is the total number of years that you have spent in education? (including any post graduate or professional qualifications)
4. How old were you when you had your first period? _____years ______months
5. Have you or anyone else in your family got scoliosis? (If so, who?)
6. Do you have any hearing difficulties?

Appendix 4– Questionnaire for participants with scoliosis

Participant_______

Questionnaire

1. What is your date of birth?
2. What is your occupation?
3. What is the total number of years that you have spent in education? (including any post graduate or professional qualifications)
4. How old were you when your scoliosis was first noticed?
5. What treatment did you have? (e.g. brace or surgery?)
6. How old were you when you had your first period? _____years ______months
7. Has anyone else in your family got scoliosis? (If so, who?)
8. What type of curve do you have? (e.g. right thoracic)
9. What is the degree of your curvature?

Do you have any hearing difficulties?

Appendix 5 - Annett Handedness Questionnaire

Handedness Questionnaire

Please indicate which hand you habitually use for each of the following activities:

Which hand do you use:

		right	left	either
1	To write a letter legibly?			
2	To throw a ball to hit a target?			
3	To hold a racket in tennis, squash or badminton?			
4	To hold a match when striking it?			
5	To cut with scissors?			
6	To guide a thread through the eye of a needle?			
7	At the top of a broom whilst sweeping?			
8	At the top of a shovel when moving sand?			
9	To deal playing cards?			
10	To hammer a nail into wood?			
11	To hold a toothbrush whilst cleaning your teeth?			
12	To unscrew the lid of a jar?			

Appendix 6–FWDT CD Tracks and headphone change

Track	Contents	Headphone change at END
Calibration		
Track 1	AAAAA	
Track 2	aaaaaa	
Practice		**Start: RED on RIGHT**
Track 3	Binaural pairs	No change
Practice/hearing		
Track 4	Monaural pairs	at end RED to LEFT
		at end RED to RIGHT
Dichotic	**Start point:**	
Track 5	Ten-pen	at end Change RED to LEFT
Track 6	Car-bar	No change
Track 7	Keg-peg	at end Change RED to RIGHT
Track 8	Toy-boy	No change
Track 9	Ten-pen	at end Change RED to LEFT
Track 10	Car-bar	No change
Track 11	Keg-peg	at end Change RED to RIGHT
Track 12	Toy-boy	No change

Appendix 7 - Critical words used in Fused Word Dichotic Task

1.	Pill	16.	Pail
2.	Bill	17.	Kit
3.	Coat	18.	Pit
4.	Goat	19.	Pier
5.	Pig	20.	Beer
6.	Dig	21.	Ten
7.	Tear	22.	Pen
8.	Deer	23.	Cook
9.	Cage	24.	Book
10.	Page	25.	Keg
11.	Pan	26.	Peg
12.	Can	27.	Toy
13.	Car	28.	Boy
14.	Bar	29.	Curl
15.	Tail	30.	Pearl

Appendix 8– Example of response sheet used in dichotic listening test.

1.	GALE	BALE	PAIL	TAIL
2.	PAN	TAN	CAN	MAN
3.	PAGE	CAGE	GAGE	RAGE
4.	KEG	BEG	PEG	LEG
5.	DEER	BEER	PIER	TEAR
6.	RAGE	CAGE	GAGE	PAGE
7.	TOOK	COOK	ROOK	BOOK
8.	BEER	TEAR	PIER	DEER
9.	BOY	TOY	COY	ROY
10.	ROY	COY	TOY	BOY
11.	MAN	PAN	TAN	CAN
12.	PIER	TEAR	DEER	PEER
13.	DEN	KEN	TEN	PEN
14.	CURL	GIRL	PEARL	BURL
15.	BAR	CAR	TAR	PAR
16.	TAN	PAN	MAN	CAN
17.	COOK	ROOK	BOOK	TOOK
18.	PAGE	RAGE	GAGE	CAGE
19.	COAT	TOTE	GOAT	BOAT
20.	ROY	COY	TOY	BOY
21.	BOAT	GOAT	TOTE	COAT
22.	CAGE	GAGE	PAGE	RAGE
23.	TEAR	DEER	BEER	PIER
24.	CURL	PEARL	BURL	GIRL
25.	TILL	BILL	PILL	GILL
26.	PAIL	GALE	TAIL	BALE
27.	TAR	BAR	PAR	CAR
28.	BOOK	COOK	TOOK	ROOK
29.	LEG	PEG	BEG	KEG
30.	FIT	PIT	BIT	KIT

Appendix 9– Ethics Committee Acceptance

University College London Hospitals **NHS**
NHS Trust

The Joint UCL/UCLH Committees on the Ethics of Human Research

Committee Alpha Chairman:
Professor André McLean

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February 5, 2002

Dear Professor McManus

Study No: **01/0132** *(Please quote in any correspondence)*
Title: **Neuropsychological correlates of adolescent idiopathic scoliosis**

Thank you for a recent letter from Ms Thorn addressing the points raised by the Chairman. We regret that we did not receive the amendments earlier, as indicated in Ms Thorn's letter.

The application is now approved by Chairman's Action. There are no further objections on ethical grounds to this study going ahead.

Please note that it is important that you notify the Committee of any adverse events or changes (name of investigator etc) relating to this project. You should also notify the Committee on completion of the project, or indeed if the project is abandoned. **Please remember to quote the above number in any correspondence.**

Yours sincerely

pp

Professor André McLean, BM BCh PhD FRC Path
Chairman

cc. Ms Tania Thorn

UCL HOSPITALS

UCL Hospitals is an NHS Trust incorporating the Eastman Dental Hospital, Elizabeth Garrett Anderson and Obstetric Hospital, Hospital for Tropical Diseases, The Middlesex Hospital, National Hospital for Neurology & Neurosurgery and University College Hospital

/ijn/February 5, 2002

Appendix 10 – Consent Form

Confidential

Consent Form
Neuropsychological Correlates of Adolescent Idiopathic Scoliosis

Researchers:

Ms. Tania Thorn
Sub-Department of Clinical Psychology
University College London,
1-19 Torrington Place,
London , WC1E 7HB.
Tel: 0207 679 1897

Prof. Chris McManus,
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Gower Street,
London WC1E 6BT.
Tel: 0207 359 1963

	Delete as appropriate:
Have you read the information sheet about this study?	Yes/No
Have you had an opportunity to ask questions and discuss this study?	Yes/No
Have you received satisfactory answers to all your questions?	Yes/No
Have you received enough information about this study?	Yes/No
Do you understand that you are free to withdraw from this study....	
*at any time	Yes/No
*without giving a reason for withdrawing	Yes/No
*without affecting your future medical care?	Yes/No
Do you agree to take part in this study?	Yes/No

Signature of participant________________________Date____________

Signature of investigator________________________Date_____________

Appendix 11 - Study Information Sheet for people without scoliosis

Confidential

Study information sheet for volunteers without scoliosis

Neuropsychological Correlates of Adolescent Idiopathic Scoliosis

Researchers:

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We are asking for your help in our research proposal. As you may know, adolescent idiopathic scoliosis (AIS) is a curvature of the spine that starts in adolescence for no apparent reason. There are a number of theories concerning the causes of AIS. One idea is that people with AIS are simply more likely to develop in a generally more asymmetrical fashion – this is called increased "developmental instability". It is also possible that increased developmental instability may be more likely to lead to AIS when someone also reaches puberty early. One implication of these ideas is that people with AIS may not only have increased spinal asymmetry, but may also have increased asymmetry in their brains.

The brain is divided into two parts, or "hemispheres". In most people, the two hemispheres tend to control different functions. For example, language is usually largely controlled by the left hemisphere and visuospatial and emotional processing are usually associated with the right hemisphere. This asymmetrical control of different functions is called "lateralisation"

There has been very little research with AIS in this area, but one previous study has found that people with AIS are more lateralised for language than other people (i.e. one side of the brain has even greater control over language than is usually the case). It has been suggested that such increased lateralisation of language may lead to differences in language ability, but this idea has never been tested in people with AIS.

This study has several goals. Most importantly, it aims to find out whether people with AIS do indeed have increased lateralisation of language and whether they have different language skills than people without AIS. Information will also be collected about developmental instability and onset of puberty, so that it should be possible to determine whether any increased lateralisation is associated with increased developmental instability and/or early maturation.

Results from this study will not only give information about the organisation of the brain in people with AIS, but will also contribute to our understanding of what causes AIS. In addition, the results from people without scoliosis will illuminate the relationship between language lateralisation and language ability, and also the relationship between developmental instability, age of maturation and cognitive ability in people without scoliosis,

The study will involve a number of tasks. Although time taken to complete these tasks will vary, we estimate that they should not take longer than an hour and a half in total. Firstly, people who participate will be asked to fill in two brief questionnaires. They will then be asked to do a "dichotic listening task". In this task, someone listens to a number of different words over headphones and have to indicate what word they have heard. After this task is completed, there will then be a number of different verbal and non-verbal tasks to complete. Finally, a palm print of the participant's hands will be taken – this will allow us to measure developmental instability by counting the number of lines on each palm print.

Obviously, in order to do this study, we need to involve people with adolescent idiopathic scoliosis. However, we also need people like you who have developed normally and do not have idiopathic scoliosis so that we have a comparison group. Gender and handedness are known to affect lateralisation, so in order to avoid this complication, we would like all our participants to be right handed women. Similarly, familiarity with English may affect language ability, so we need all our participants to speak English as a first language.

You do not have to take part in this study if you do not want to. If you decide to take part you may withdraw at any time without having to give a reason. All the information you give us is confidential. It will be kept separately from your name and referred to only by a code number.

All proposals for research using human subjects are reviewed by an ethics committee before they can proceed. This proposal was reviewed by the Joint UCL/UCLH Committees on the Ethics of Human Research.

If you have any questions about this study, please contact Tania Thorn on 07967 596 056 or by e-mail at tania.thorn@aol.com

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