IMPAIRED MOTOR SKILL AND PERCEPTION IN CHILDREN

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To Patricia

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ABSTRACT

Previous studies, requiring that subjects reproduce the length of a standard stimulus, have found that impaired motor skill in otherwise normal children is associated with a perceptual defect in the visual modality. No clear evidence of a similar defect was found in the kinaesthetic modality, or in the translation of information between modalities, but this may have been because of differences in strategies used by subjects; and because of reliance on absolute error as a measure of performance. These issues were investigated in the experiments reported in this thesis.

Methodological factors were investigated in Experiments 1 to 3 using adult subjects and in Experiments 4 and 5 using children as subjects. In addition, Experiments 4 and 5 examined relationships between motor ability and perceptual judgements in the visual and kinaesthetic modalities, and the translation of information between these modalities. Experiment 6 investigated a possible association between impaired motor skill in children and their ability to judge locations in space, and to translate location information between the visual and kinaesthetic modalities.

Although subjects in Experiments 1 and 2 were instructed to reproduce the length of a standard stimulus, irrespective of whether vision or kinaesthesis was involved, error patterns showed that they tended to reproduce the length of a line presented in the visual modality (a "distance" strategy), but the location of the end-point of a movement presented in the kinaesthetic modality (a "location" strategy). It was also found that contextual effects can influence perceptual judgement in experiments of this design. Further, the results indicated that absolute error is not an appropriate measure of performance in tasks of this type and that, instead, residual error is a preferred alternative.

In Experiment 3 subjects were instructed to reproduce either the length or the location of a standard stimulus and, consistent with earlier findings, the results showed that these strategies were associated with differences in error pattern. Also, accuracy was affected by both the modality in which the standard stimulus was presented and suitability of modality to strategy. These findings were confirmed by the results of Experiments 4 and 5. It was concluded that it is difficult to design an experiment of this type in which all possible confounding variables are excluded, but that the use of strategy can be controlled and the effect of contextual factors can be eliminated by the use of residual error as a measure of performance.

Moderately strong correlations between accuracy in reproduction of standard stimuli and motor ability were found in Experiments 4, 5 and 6 for judgements of location within both the visual and kinaesthetic modalities, suggesting that ability to make such judgements contributes to motor skill. Similarly, moderately strong correlations were found when a translation of location information between modalities was required, suggesting that this ability also contributes to motor skill. In Experiment 6 children with impaired motor skill were found to be less accurate than their controls when reproducing standard stimulus locations within both the visual and kinaesthetic modalities, and when a translation of location information was required. Reproduction of standard stimulus locations was less accurate when a translation between modalities was required, as compared with within-modal reproduction, but this was equally so for both groups. Thus, the findings of this experiment suggested that impaired motor skill in children is associated with a perceptual defect, but not with a defect in the translation process.

The results of Experiment 6, therefore, extend earlier findings by suggesting that impaired motor skill in children is associated with a perceptual defect that is not modality specific and, in particular, affects ability to judge locations in space. However, evidence of such an association does not necessarily indicate causality. Moreover, although every attempt was made to exclude possible confounding variables, it remains that there are potential problems with experiments of this design. It was suggested that future research should be directed to the use of a visual pursuit tracking task, together with disruption of feedback.

STATEMENT

This thesis contains no material which has been accepted for the award of any other degree of diploma in any University and, to the best of my knowledge and belief, the thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

I consent to the thesis being made available for photo-copying and loan if accepted for the award of the degree.

T.R. Smyth

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CHAPTER 1
IMPAIRED MOTOR SKILL

Impaired performance of motor skills can result from a number of disorders (Gordon & McKinlay, 1980; Reuben & Bakwin, 1968). For example, disorders such as congenital dislocation of the hip, muscular dystrophies, Gerstman's syndrome, or Sydenham's rheumatic chorea, among others, can result in motor impairment (Wilson, 1974), as can intellectual disability (Montgomery, 1981; Francis & Rarick, 1959; Howe, 1959). There are, however, some children who suffer from no identifiable physical disorder and who are of normal intelligence, but who demonstrate unusual difficulties with the performance of motor skills.

Terminology

A variety of terminology has been used to describe this problem. For example, these children have been described as motor impaired (Whiting, Clarke & Morris, 1969), motorically awkward (Williams, Fisher & Tritschler, 1983) or developmentally dyspraxic (Dawdy, 1981), and the disorder has been referred to as congenital apraxia (Orton, 1937), developmental dyspraxia (Gomez, 1972; Lesny, 1980a), developmental dyspraxia-dysgnosia (Lesny, 1980b), developmental apraxia and agnosia (Gubbay, 1973; Walton, Ellis & Court, 1962), visuo-motor disability (Dare & Gordon, 1970; Brenner, Zangwill & Farrell, 1967), visuomotor incoordination (Wilson, 1974) and perceptual-motor difficulties (Domrath, 1968), among other terms. Commonly, however, these children are described as 'clumsy', a term first used by Orton (1937) and since adopted by a number of authors (e.g. Dare & Gordon, 1970; Geuze & Kalverboer, 1987; Gubbay, 1973; Hall, 1988; Henderson, 1987; Hulme & Lord, 1986; Illingworth, 1963; Keogh, Sugden, Reynard & Calkins, 1979; van Dellen & Geuze, 1988; Walton, 1961, 1963).

Some authors (Taylor & McKinlay, 1979; Henderson & Hall, 1982; Laszlo, Bairstow, Bartrip, & Rolfe, 1988) suggest that, because of its pejorative connotations, the word clumsy should not be used to describe these children. In particular, Taylor and McKinlay (1979) comment that the colloquial and medical sense of the word can be confused, and Henderson and Hall (1982) suggest that there is a need for a more accurate description of the condition. It would be more appropriate to describe these children simply as 'motor impaired', but the term clumsy is concise, descriptive and has most commonly been used.

Definition

Although there is general agreement on the main points, definitions of clumsiness vary, as is illustrated by the following examples:

> clumsiness may be defined as a difficulty in skilled purposive movement which is inappropriate for the child's age and cannot be explained in terms of general intellectual impairment or gross sensory defects. (Hulme, Biggerstaff, Moran and McKinlay, 1982a, p. 461)

> the 'clumsy child' must possess a normal bodily habitus and intellect but exhibits an impairment of skilled, purposive movement unassociated with routine conventional neurological signs. Therefore, there must be an absence of ataxia, involuntary movement, weakness, sensory loss or spasticity. (Gubbay, 1989, p. 14)

The central point of these definitions is that motor skill is impaired, but this impairment cannot be attributed to any identifiable physical or intellectual disorder. In brief, the clumsy child can be described as one who is clumsy, but otherwise normal. Children who suffer from identifiable disorders, however, have not always been excluded. For example, Abbie, Douglas and Ross (1978) included children in their study who suffered from disorders such as triplegia, hypotonia, hydrocephalus, intellectual disability and acquired brain injury, among others, and Søvik and Maeland (1986) included some children whom they considered to be borderline cases of intellectual disability. However, it is clear that children suffering from such disorders should not be included in the category of clumsy children as defined here.

A problem with any definition is specifying the level of performance at which motor skill can be said to be impaired. Motor ability can be expected to be normally distributed (Hall, 1988), and children vary widely in their ability to perform motor skills (Gubbay, 1975a; Gordon, 1977; Abbie et al., 1978). Consequently, there is no generally accepted level of performance which distinguishes motor impairment (Gordon & McKinlay, 1980), and so there can be no absolute definition (Hulme & Lord, 1986). The determination of impaired motor skill, therefore, can only be made on an arbitrary basis (Keogh et al., 1979).

Differing views on what constitutes clumsiness have been expressed. For example, Cooke (1978) suggests that the disorder is demonstrated by "a variety of minor motor handicaps" (p. 101), whereas Hulme and Lord (1986) suggest that clumsy children have "severe and specific problems in developing adequate skills of movement" (p. 257). More specifically, when testing children's motor abilities investigators have used differing criteria. For example, Brenner and Gillman (1966) set their cut-off at the 15th percentile, Gubbay (1973) used the 10th percentile for individual test items, and Keogh (1968) allocated a low mark if the score on an item was below the 10th percentile and a marginal mark if the score fell between the 10th and 30th percentiles.

Prevalence

Not surprisingly, given his more lenient criterion, Keogh (1968) identified 11 (19%) of the fifty-eight 9-year-old boys in his study as at least marginally clumsy, although he considered only 4 (6.9%) to be severely affected. This latter figure is similar to the prevalence suggested by the findings of other studies using large samples, the results of which are summarized in Table 1.1. Based on these findings, although the prevalence found in the Johnston, Short and Crawford (1987b) study is somewhat higher, the best estimate is that about 6% of ordinary children have some degree of fairly severe motor impairment.

Table 1.1

Proportion of Children Identified as Clumsy in Surveys

Survey	**Age (years)**	**Sample N**	**Identified N**	**%**
Brenner & Gillman (1966)	8- 9	810	56	6.9
Gubbay (1973)	8-12	919	56	6.1
Søvik & Maeland (1986)	9	331	19	5.7
Johnston et al. (1987b)	5	717	55	7.7
Johnston et al. (1987b)	7	757	77	10.2

An additional problem, which can affect estimates of the prevalence of clumsiness, is that cultural differences influence the acquisition of motor skills. For example, Hindley, Filliozat, Klackenberg, Nicolet-Meister and Sand (1966) found differences in the age of walking between children in five European cities. Also, by comparison with American children, Goldberg (1972) found that Zambian children reached motor milestones earlier, and Hamilton (1981) found that Australian Aboriginal children were more advanced than Anglo-Australian infants. To what extent these differences are the result of heredity or environment remains unclear. Nonetheless, it is reasonable to accept that experiential factors play a role. In some cases, therefore, a child's apparent clumsiness could be attributed to a slower than average acquisition of motor skills within a cultural setting.

Knuckey and Gubbay (1983) retested 20 of the children identified eight years previously in the Gubbay (1973) study, together with their matched controls, and found that only seven (35%) of the clumsy group still differed significantly from their controls. Moreover, all of the subjects in this group of seven had been originally classified as severely affected, whereas the remaining subjects had been classified as mildly or moderately clumsy. This finding suggests that about one-third of the 6% of children identified as clumsy by Gubbay (1973) had difficulties with motor skills that continued beyond childhood, resulting in an estimate that about 2% of the population suffer from persisting motor impairment.

Tests of Motor Impairment

Although a number of tests of motor ability have been developed (for a review see Laszlo & Bairstow, 1985; Henderson, 1987), no one test has been generally accepted. Tests have been developed for a specific purpose. For example the South Australian Motor (SAM) Test (Johnston, Crawford, Short & Smyth, 1987a; Smyth, Johnston, Short and Crawford, 1991) was developed as a screening test for 5-year-olds. Some investigators have devised tests for use in their research (e.g., Brenner and Gillman, 1966; Keogh, 1968; Roussounis, Gaussen & Stratton, 1987). Others have adopted a modification of an existing test. Henderson and Hall (1982), for instance, used items from the Stott, Moyes and Henderson (1972) Test of Motor Impairment. However, the Gubbay (1973) test, or slightly modified versions of it, has most commonly been used in research (e.g. Erhardt, McKinlay & Bradley, 1987; Hulme et al., 1982a: Hulme, Smart, Moran & Raine, 1983; Hulme, Smart, Moran, & McKinlay, 1984; Johnston et al., 1987a; Lord & Hulme, 1987a, 1987b; Murphy & Gliner, 1988; Short et al., 1984; Søvik & Maeland, 1986).

Laszlo and Bairstow (1985a) are critical of the Gubbay (1973) test, on the grounds that not all of the children identified as clumsy by Gubbay were thought by class teachers to be so. However, as will be discussed later, subjective judgements can be expected to be unreliable. Also, Gubbay found a statistically significant difference between scores on test items for children identified as clumsy and their controls. In its original form, the Gubbay test included eight items (for a detailed description see Gubbay, 1973, 1975b). In a later study, Gubbay (1978) tested 19 children who had been referred to hospital because of their clumsiness, and he found that in all cases one of four items produced a score in the bottom 5% of his range of normal performance. On the basis of this finding, Gubbay concluded that the test could be reduced to these four items. Further, Hulme et al. (1982a, 1982b, 1983) used these items in studies of clinically identified clumsy children, and they found that all effectively discriminated between clumsy and control children. These four test items, together with one additional item from his original eight, have been incorporated by Gubbay (1989) in a revised version of his test.

A weakness of the early Gubbay (1973) test was the absence of normative data for children below the age of eight years. Gubbay (1989) includes normative data for 6 and 7-year-old children. However, he derived these norms from data collected from 6 and 7-year-old children in his original 1973 study (personal communication) and in that study he discarded these children, because "it became apparent that the screening tests were not sufficiently critical in the lower age ranges." (Gubbay, 1973, p. 20). Therefore, the normative data which Gubbay gives for 6 and 7-year-old children may not be valid.

Ehrhardt et al. (1987), using a sample of 885 English children aged from 6 to 11 years, calculated normative data for a slightly modified version of the Gubbay (1973) test, including only the four items suggested by Gubbay (1978). The resulting data differed somewhat from Gubbay's. In particular, Erhardt and his colleagues report that Australian children seem to be better in gross motor tasks, whereas English children seem to be better in fine motor tasks. Although, then, Erhardt and his colleagues included 6 and 7-year-old children in their study, because of the difference found between Australian and English children's scores, it is questionable to use their normative data in Australia. Moreover, they included in their study only the four items suggested by Gubbay (1978). Short et al. (1984), however, have calculated normative scores in Australia for the five items of the Gubbay (1989) test, using a sample of three hundred and sixty-five 7-year-old children. Thus, the five-item Gubbay test can be used to assess the motor ability of 7 to 12-year-old children in Australia.

The normal distribution of motor ability, variability in rate of development, and cultural differences, however, remain problems for any test of motor ability. Therefore, it is questionable whether or not such tests can validly identify children who suffer from impaired motor skill. Nonetheless, the available tests provide the only subjective and quantifiable measure of motor ability.

Male Preponderance

In clinical studies a number of authors have reported finding a greater prevalence of clumsiness in boys than girls (Abbie et al., 1978; Baker, 1981; Gubbay et al., 1965; Gubbay, 1978; Gordon & McKinlay, 1980; Knuckey et al., 1983). Gordon and McKinlay (1980), for example, report that in their study clumsy boys outnumbered girls in a ratio of 4:1. By comparison, in surveys of children in ordinary schools, Brenner and Gillman (1966) and Gubbay (1975b) report finding no difference between the proportion of boys and girls classified as clumsy. Similarly, Johnston et al. (1987a) report that males and females were equally represented in their sample of 7-year-old clumsy children. However, Søvik and Maeland (1986) identified more clumsy boys than girls in their survey, and Johnston et al. (1987a) found that, in their 5-year-old group, clumsy boys outnumbered girls in a ratio of 2:1.

It could be argued that the absence of a difference between male and female prevalence, in the findings of some surveys, is attributable to a test bias in favour of males. For example, Johnston et al. (1987a) found no sex difference in their 7-year-old children using the Gubbay (1973) test, but a male preponderance in their 5-year-olds using the DIAL test (Mardell & Goldenburg, 1975). However, in both the Gubbay (1975b) and the Søvik and Maeland (1986) studies the Gubbay (1973) test was used and, although in the former there was no difference between the proportion of boys and girls found to be clumsy, in the latter there was a distinct male preponderance. Moreover, Ehrhardt et al. (1987) found that boys and girls performed equally well on the Gubbay test. Although, then, the findings of clinical studies, and of the Søvik and Maeland (1986) survey suggest that more boys than girls are clumsy, the presence of such a difference has not yet been convincingly shown. Moreover, there has been no satisfactory explanation for a male preponderance of clumsiness (Geuze & Kalverboer, 1987).

An alternative explanation of clinical reports of a male preponderance is simply that more clumsy boys than girls are referred for medical attention. For example, it is possible that boys tend to be more boisterous, so that their disability is more readily noticed, and Gordon and McKinlay (1980) suggest that the behaviour of clumsy boys may be more difficult to manage. Sugden (1975) found that kindergarten teachers identified at least three times more boys than girls as clumsy, and Henderson and Hall (1982) report that of 16 clumsy children identified by infant school teachers, 13 were boys. It is possible, then, that impaired motor skill is more apparent in boys than girls.

Recognition

Because clumsiness is an accepted feature of early childhood and there is a wide range of motor ability among young children, unless the child's difficulties are severe they may not cause concern (Abbie et al., 1978; Gordon, 1977). Clumsy children's problems are, however, likely to become evident when they start school. At this time children are faced with a range of demands on physical skills, such as cutting with scissors, drawing, running, hopping and ball skills, which are a normal part of school life. Moreover, the child's performance is readily compared with that of his or her peers. Nonetheless, it is difficult to recognize the clumsy child.

Keogh et al. (1979) found a correlation of .47 between kindergarten teachers' assessment of clumsiness and the results of a test of motor ability, but a correlation of .69 for physical education specialists, suggesting that physical education specialists are more able to identify difficulties with motor skills than are kindergarten teachers. However, not all of the children classified as clumsy on the basis of the motor ability test were identified by either classroom or physical education teachers. Similarly, in a survey of 9-year-old children, Søvik and Maeland (1986) found that class teachers identified 21 children as being clumsy, but only eight of these children were so categorized on the basis of a test of motor ability. Moreover, seven children who were not considered by teachers to have problems were identified as being clumsy on the basis of the motor ability test. Further, Johnston et al. (1987a) found that, in their sample of 5-year-old children, of 186 who were thought by teachers to have difficulties with motor skills, less than half were subsequently identified as clumsy on the basis of a test of motor ability.

By comparison, Henderson and Hall (1982) report finding a "remarkably high" level of agreement between identification of a sample of 16 clumsy children by kindergarten teachers, a paediatrician, and a test of motor ability. However, on a subjective basis the paediatrician classified three clumsy children as having normal motor ability, and one child from a control group as clumsy. More importantly, although clumsy and control children differed significantly on all test items, Henderson and Hall set no criterion to identify clumsy children. As a consequence, neither the teachers' nor the paediatrician's classifications can be assessed on an objective basis.

It has already been suggested that available tests are unsatisfactory because of the normal distribution of motor ability, variability in rate of development, and cultural differences. A further problem is that test items such as threading beads within a specified time, or executing a required number of hops (which are typical test items), can result in a score which falls within the normal range, but the child may perform such tasks in an awkward manner. Consequently, whereas the test score would indicate that the child has normal motor ability, an experienced observer would classify the child as clumsy. This could account for the reported findings of children being identified as clumsy on a subjective basis, but not so on an objective basis. However, this does not explain the finding that some children who are subjectively classified as having normal motor ability are objectively identified as clumsy. This problem has been addressed in the Stott, Moyes and Henderson (1984) revision of their test, which incorporates assessments of performance such as immature motor patterns, poorly established laterality, and muscular tension. Nonetheless, the problems of variability in motor skill and subjectivity remain, and so the identification of the clumsy child is problematic.

Characteristics

The clumsy child's difficulties can be expected to be evident in a wide range of motor skills. For example, these children have been reported as walking awkwardly (Arnheim & Sinclair, 1975), running and jumping awkwardly (Walton, Ellis and Court, 1962), frequently falling and dropping things (Gordon, 1969), having difficulty with dressing (Walton et al., 1962), doing up buttons and shoelaces awkwardly (Dare & Gordon, 1970), using eating utensils awkwardly (Gordon & McKinlay, 1980), having difficulties with drawing (Walton, 1961), and having poor handwriting (Illingworth, 1963). In addition, clumsy children have sometimes been reported as having defects of speech (e.g., Brenner, Gillman, Zangwill & Farrell, 1967; Henderson & Hall, 1982).

Some children may have problems only with fine motor skills (Mellor, 1980; Henderson, 1987). By comparison, Henderson and Hall (1982) report that a clumsy boy in their study could draw as well as normal controls, but had very poor gross motor skills. Further, a child's difficulties can be surprisingly specific. Gordon and McKinlay (1980) comment that "The child may not be able to write neatly for example but may be able to sew and do jigsaw puzzles without difficulty." (p. 4). Such cases, however, are rare. Typically, the clumsy child will have difficulties over a range of motor skills. For example, in a review of clumsy children referred over a period of seven years, Baker (1981) remarks that both fine and gross motor skills were affected.

Gordon (1982) suggests that, when children are severely clumsy, their difficulties may be recognized by parents or kindergarten teachers. In such cases it is likely that the child will be referred for medical attention. For example, Abbie et al. (1978) report that clumsiness was the most common reason for referral of the 176 cases in their study, and Gubbay (1978) reports that the 39 children in his study had been referred because of their clumsiness. Some children, however, will have only minor difficulties (Henderson, 1987) and so their problems may not attract attention. For example, of the 56 clumsy children identified by Gubbay (1975a), none had been referred for medical attention.

Clumsy children frequently attract attention for reasons other than impaired motor skill. Gordon and McKinlay (1980) comment that these children are often referred for medical attention because of symptoms of anxiety, and Hall (1988) has remarked that sometimes children are referred because they are "sad or socially inept". Often poor academic performance can be the cause of concern. For example, Hulme et al. (1982a) comment that the 16 clumsy children in their study had been referred because of school failure. In other instances medical attention has been sought because of suspected intellectual disability (Gordon, 1969) and the disorder may be misdiagnosed as such (Illingworth, 1963; Walton, 1963).

Intelligence

Using a sample of 762 children, Brenner and Gillman (1966), compared performance on a battery of motor tasks (including drawing, cutting with scissors and a block design task) with intelligence. In this study correlations between task performance and IQ ranged from .09 to .37, the correlation with the score for the complete battery of tests being .49 for boys and .46 for girls. These findings suggest that, although ranging from very low to moderate, there is a relationship between performance in motor skills and IQ. Some clumsy children have low intelligence (Baker, 1981; Dare & Gordon, 1970; Gordon, 1969; Illingworth, 1963), but it is not the case that low IQ will necessarily result in poor performance, Wilson (1974) suggesting that a problem is unlikely unless the child's IQ is below 50; and a child with IQ this low would not be categorized as clumsy, as defined here.

A problem with clinical studies is that, since it is likely that only the more severely affected child will be referred for medical attention, and often attention is sought because of problems with school work or suspected intellectual disability, low intelligence may be more characteristic among such children. Also, in some cases children have been inappropriately diagnosed as clumsy. For example, in the Abbie et al. (1978) study the impaired motor skill of some children was attributed to severe intellectual disability. However, Baker (1981) reports that the majority of clumsy children in her study were of normal intelligence, which suggests that low intelligence is not typical of these children. Nonetheless, Gubbay (1975a) found that, compared with controls, a significant number of clumsy children in his study had an IQ of below 80.

The intelligence scores of clumsy children can, however, be distorted by poor results in the performance items of an intelligence test. A number of authors have reported that the scores of clumsy children on the performance subscale of the Wechsler Intelligence Scale for Children (WISC) have been lower than those on the verbal subscale (Brenner et al., 1967; Gordon, 1969; Gubbay et al., 1965; Walton, 1961, 1963; Walton et al., 1962; Wilson, 1974). Moreover, where the verbal IQ scores of clumsy children and their controls were compared, no significant difference was found (Hulme et al., 1982a, 1982b; Lord & Hulme, 1987a, 1987b, 1988; Henderson & Hall, 1982). By comparison, in some studies the performance IQ of clumsy children has been found to be significantly lower than that of their controls (Hulme et al., 1982a, 1982b; Lord & Hulme 1987a, 1987b, 1988).

This superiority of verbal over performance IQ is not, however, found in all cases. For example, Gubbay et al. (1965) found, in their sample of 14 clumsy children, that verbal IQ was superior to performance IQ for 11. Henderson and Hall (1982) also found this pattern in only seven of their sample of 16 clumsy children, whereas for six children they found that performance IQ was superior to verbal IQ, i.e. the opposite pattern. Moreover, Henderson and Hall found no significant difference in performance IQ between their clumsy and control children. Although, then, superiority of verbal over performance IQ is a common finding in clumsy children, as is lower than normal performance IQ, these patterns are not found in all cases.

Clumsy children are frequently reported to have difficulty with perceptual tasks (Gordon, 1969). For example, Walton (1963) found that clumsy children had difficulty with tasks such as recognizing objects or fitting blocks into appropriately shaped holes, and Gordon (1982) suggests that these children have difficulty in recognizing and sequencing shapes. Further, Lord and Hulme (1987) investigated the visual perception of a sample of 16 clumsy children, using a battery of tests, and found evidence of a visual perceptual defect. Since the tasks included in the performance subscale of the WISC involve visual perception, it is not surprising that clumsy children are often reported as performing at a below normal level on this subscale. Lower than normal full-scale IQ in these children, therefore, can result from perceptual difficulties affecting their performance subscale score.

Academic Ability

Although by definition clumsy children have normal intelligence, Gordon (1982) has remarked that often there is an overlap between clumsiness and learning difficulties, including reading (Baker, 1981; Henderson & Hall, 1982; Søvik & Maeland, 1986), spelling (Baker, 1981; Brenner & Gillman, 1966; Brenner et al., 1967; Søvik and Maeland, 1986), and arithmetic (Baker, 1981; Brenner & Gillman, 1966; Brenner et al., 1967; Gubbay et al., 1965). However, these problems are not necessarily attributable to learning difficulties associated with a low level of intelligence.

Since clumsy children often are reported to have speech difficulties (Brenner et al., 1967; Gordon, 1969; Gubbay, 1978; Gubbay et al., 1965; Orton, 1937; Walton, 1961; Walton et al., 1962), it is possible that assessment of reading at school may be distorted by problems of articulation. Also, clumsy children often have poor and sometimes illegible handwriting (Brenner et al., 1967; Gordon, 1969; Gubbay, 1978; Henderson & Hall, 1982; Orton, 1937; Søvik and Maeland, 1986; Walton et al., 1962), and Brenner et al. (1967) have remarked that, in their study, the problems that clumsy children experienced with arithmetic were associated with the layout of written work rather than with basic principles. It is likely, then, that the difficulties that some children experience with academic work can be attributed to their impaired motor skill. Further, since it has been suggested that clumsiness is associated with a visual perceptual defect, it is possible that such a defect also impairs academic performance.

Not all clumsy children, however, experience such difficulties. For example, Brenner and Gillman (1966) noted that the majority of the 56 clumsy children in their sample were good readers and Henderson and Hall (1982) found that, in their sample of 16 clumsy children, although eight had reading skills that were below those for their chronological age, another eight had good reading scores. Also, Lord and Hulme (1987a) found no significant difference, between a sample of 16 clumsy and 16 matched controls, in scores on reading and spelling tests. Nonetheless, it is likely that the academic performance of clumsy children will be affected by effects of the disorder that are not immediately apparent.

Associated Effects

Proficiency in motor skills is an important determinant of the status afforded children by their peers (Eason, Smith & Steen, 1978; McMath, 1980). Consequently, because of their poor performance in sports and games, clumsy children are likely to be unpopular (Gordon, 1982; Henderson & Stott, 1977) and they may be regarded as a "figure of fun" (Gordon, 1969). Moreover, because of the absence of an obvious cause for the child's difficulties, the attitude of adults also may be unsympathetic (Gubbay, 1989).

Parents may accept the child's clumsiness, but it is likely that problems such as frequently dropping things, difficulties with dressing, and messy eating, will lead to frustration. Some parents may set unrealistic expectations and be dissatisfied when the child fails (Arnheim & Sinclair, 1975), and the difficulties which these children demonstrate can be a great disappointment to athletic parents (Gordon, 1982). Also, problems at school with reading and writing can lead to parental worry or anger (Frostig, 1963). Similarly, the attitude of teachers may not be sympathetic. For example, Brenner et al. (1967) comment of the clumsy children in their study that, "Many of these children tended to be described by teachers as particularly irritating, difficult, lacking in self confidence, and unpopular with their peers." (p. 261).

It is probable, then, that clumsy children will adopt a diffident attitude to manual skills (Gubbay et al., 1965) and that they will develop a dislike and avoidance of those activities that demonstrate their deficiencies (Whiting et al., 1969; Gordon, 1977). For example, sport and physical education classes may be dreaded (Gordon & McKinlay, 1980) and truancy may be frequent (Henderson & Stott, 1977). Consequently, clumsy children are likely to adopt passive pursuits (Gubbay, 1989) and lack of practice would be expected to impede the acquisition of motor skills. Further, Cornish (1980) has observed that the physical strength of clumsy children is below normal, which can be attributed to lack of physical exercise. Again, lack of strength can be expected to restrict the performance of some skills. In addition, poor fine motor skill can affect the child's choice of hobbies (Gordon & McKinlay, 1980). For example, Brenner et al. (1967) found that none of the 14 clumsy children in their study enjoyed hobbies that required fine motor skills, whereas 11 children in their control group enjoyed such activities.

Secondary Emotional Problems

Some clumsy children adjust to their difficulties (Henderson & Stott, 1977) and others are scholastically successful and so compensate for their lack of motor skill (Brenner and Gillman, 1966; Orton, 1937). However, regardless of level of intelligence, it is likely that these children will experience secondary emotional problems. Clumsy children may be trying hard, but their efforts are not recognized (Gordon, 1977), and it is probable that they will continually be reminded of their failure (Whiting et al., 1969). Consequently, feelings of incompetency, inadequacy, depression, frustration and anxiety are likely (Eason et al., 1978; Frostig, 1963; Gordon, 1977, 1982; Gubbay et al., 1965; Henderson & Stott, 1977; Whiting et al., 1969).

As a result of their frustration, clumsy children may seek avenues for achievement and recognition that may be socially undesirable, and that may aggravate their problems (Gubbay et al., 1965; Whiting et al., 1969). Some children, instead of withdrawing from difficult situations, may "play the role of a clown", and become a nuisance and distraction in class, or become hostile and aggressive (Frostig, 1963; Mellor, 1980). Behaviour problems, including rapid swings of mood, inability to concentrate and generally unrestrained behaviour, have been reported in clumsy children (Brenner et al., 1967; Dare & Gordon, 1970; Gordon, 1969; Gubbay, 1978; Gubbay et al., 1965). These problems are thought to be a consequence of the child's difficulties with motor skills (Wilson, 1974) and are considered to be secondary disturbances resulting from frustration in otherwise intelligent children, due to lack of recognition of their problem (Gubbay et al., 1965; Gordon, 1969, 1977, 1982). Anxiety is likely to be an additional problem, and Mellor (1980) comments that symptoms such as non-organic pain, vomiting or nausea are common. The secondary emotional effects of abnormal clumsiness can, however, be more subtle.

Kinsbourne (1973) comments that anxiety results in poor concentration, and Gordon (1982) suggests that learning can be detrimentally affected by depression. Further, expectancy of failure can have a detrimental effect on children's learning (Osler, 1954). Since clumsy children can be expected to fail frequently in tasks involving motor skills they will be keenly aware of their difficulties (Eason et al., 1978). The effects of failure and rejection on the child's self esteem and self concept can therefore be significant (Baker, 1981; Brenner et al., 1967; McMath, 1980; Shaw, Levine & Belfer, 1982). This is particularly so when the child not only has difficulties with the performance of motor skills, but is also in the lower range of intelligence, such children being described by Shaw et al. (1982) as being "doubly jeopardized". Secondary emotional problems, however, can be expected to affect all clumsy children. Brenner and Gillman (1966) comment of the children in their study that their academic progress did not seem to be satisfactory in relation to their intelligence, and

Baker (1981) has similarly commented of the children in her study that they were "underachieving educationally". Further, Brenner et al. (1967) report the case of a clumsy boy who had a verbal IQ of 128, but who refused to sit for an examination because of his anxiety about arithmetic.

Short, Crawford and Johnston (1984) found little difference between the prevalence of behaviour problems in a sample of 56 clumsy 5-year-old children and the population norm, but they found that behaviour problems were more prevalent in a sample of 48 clumsy 7-year-olds. Similarly, they found no evidence of poor self concept in their sample of 5-year-old clumsy children, but in their 7-year-old group poor self concept was more prevalent than would be expected. This suggests that the secondary emotional problems associated with clumsiness develop during the early school years. It is important, then, that the cause of the child's difficulties is recognized early so that these secondary emotional effects can be avoided, or at least minimized, by a sympathetic understanding of the child's problems (Gubbay, 1978).

Problem

Because of its associated and secondary emotional effects, then, impaired motor skill in children is an important problem. Although it has been suggested that some motor impaired children are scholastically successful and so compensate (Orton, 1937), that some adjust to their difficulties (Henderson & Stott, 1977), and that the majority cope (Gordon & McKinlay, 1980), it is apparent that impaired motor skill can have a deleterious effect on some children. In particular, it is likely that, as a result of their motor impairment, many children do not achieve their full potential. Therefore, it is important that the cause of the affected child's difficulties be understood so that appropriate help may be given.

Impaired motor skill in children has long been recognized. Orton (1937) remarked that the problem was recognized by Galen, the early Greek physician. Attention was drawn to the disorder by Orton and more recently by Walton (1961, 1963) and Walton et al. (1962). However, as Hulme and Lord (1986) remark, since then interest in the problem has developed relatively slowly. In recent years a number of papers on clumsiness in children have been published by authors from a range of disciplines, but the literature is mainly derived from cases identified in either clinical studies or surveys. There have been only relatively few reports of experimental research, and the cause of impaired motor skill in these children remains unclear.

CHAPTER 2
CAUSES OF CLUMSINESS

It has been suggested that clumsy children are simply those whose motor skill falls within the lower range of a normal distribution (Hall, 1988). However, any distribution merely reflects what is found in the population and provides no causal explanation. Whilst in some cases poor motor skill may be characteristic of normal variation, in others (as was discussed in Chapter 1) the problem can be attributed to some disorder. To explain abnormal clumsiness simply on the basis of a normal distribution, therefore, is not satisfactory.

Developmental Delay

Rutter and Yule (1970) propose that clumsiness represents a delay in the development of normal functions and, consistent with this suggestion, clumsy children are frequently reported to have been late developers (e.g., Brenner & Gillman, 1966; Gordon, 1969, 1982; Gordon & McKinlay, 1980; Gubbay, 1978; Gubbay et al., 1965; Illingworth, 1963; Orton, 1937). For example, Knuckey et al. (1983) found that, of 51 clumsy children, delayed motor milestones had been noted in 42. Also, children referred for medical attention commonly have been in the younger age range. For example, in the Abbie et al. (1978) study the majority were 7 years old or less, and Baker (1981) reports that in her study most were between 7 and 9 years of age. Although these reports suggest that clumsiness may be associated with a developmental delay, it is generally recognized that there are substantial differences in the ages at which motor milestones are reached. Moreover, in the Gubbay (1978) study cases of clumsiness ranged up to 18 years, and the findings of the Knuckey and Gubbay (1983) study show that, for those who are more severely affected, impaired motor ability persists beyond childhood.

A problem with clinical studies is that, because of variation in the definition of clumsiness, it is not clear that all of the children included are clumsy as defined here. In the Abbie et al. (1978) study, for instance, impaired motor skill was attributed to a number of disorders. Also, not all clumsy children are referred for medical attention. For example, Brenner et al. (1967) report that, although the 14 children in their study had long been regarded as being awkward or backward, only one boy had been referred for medical attention, and then because of an emotional problem, rather than as a result of his difficulties with motor skills. Further, marked difficulties with motor skills are likely to be noticed when children start school (Abbie et al., 1978; Gordon, 1977). Consequently, it is probable that only more severely affected children will be referred for medical attention and that they will be in the younger age range. Thus, the apparent preponderance in clinical studies of clumsiness in the younger age range may not be representative of the prevalence of the disorder across age in the population.

To attribute impaired motor ability to a slower than normal rate of development, on the basis of either reports of delayed motor milestones or of the ages of children in clinical studies, therefore, is questionable. Moreover, a developmental delay hypothesis does not explain why the acquisition of motor skills is delayed. Whilst in some cases a child's apparent clumsiness may be attributable to normal variation in the acquisition of motor skills, in others the child's difficulties may be attributable to some defect.

Brain Damage

Impaired motor skill can result from brain damage. Some children in the Abbie et al. (1978) study, for example, had been referred following head injury as a result of vehicular accident. Such cases would be excluded from the category of abnormal clumsiness as defined here but, as Gesell and Armatruda (1947) point out, in its mildest form brain injury may be so delicate that it must be implied on the basis of clinical signs. That is, the damage is thought to be minimal and hence has been referred to as minimal brain damage or dysfunction (MBD). Gubbay (1975b), however, comments that this condition is more often implied rather than proven, and Connolly (1980) remarks that the concept "appears to be untestable". (For a critical discussion see Rie & Rie, 1980.) Nonetheless, abnormal clumsiness in children has sometimes been attributed to MBD (Dare & Gordon, 1970; Whiting et al., 1969).

Perinatal complications could result in brain damage (Wilson, 1974; Gordon, 1982; Arnheim and Sinclair, 1975), and such complications have been noted frequently in clinical reports of clumsy children (e.g., Abbie et al., 1978; Gordon, 1969; Gubbay, 1978; Gubbay et al., 1965; Prechtl & Stemmer, 1962; Walton, 1961; Walton et al., 1962; Wilson, 1974). For example, Gordon (1969), comments on the high incidence of problems such as short gestation, anoxia at birth, bleeding during pregnancy, head injuries and jaundice in early infancy. Such predisposing factors are accepted features of established cerebral palsy (Gesell & Armatruda, 1947), and so it is not surprising that this disorder has sometimes been associated with clumsiness in children. For example, Illingworth (1963) reviewed 27 cases, concluding that they were examples of "truly minimal cerebral palsy" and

Gubbay et al. (1965) concluded that, of 21 children in their study, seven had "a form of minimal cerebral palsy".

In contrast, Gordon (1969) comments that, whilst slight evidence of cerebral palsy is sometimes found, this is exceptional. However, Gubbay et al. (1965) pointed out that, among the children in whom they did not diagnose minimal cerebral palsy, there was a high incidence of predisposing factors such as anoxia and birth injury, which are accepted features of the disorder, and they proposed that there is a clinical overlap. More recently, Gordon (1982) has similarly commented that there is no clear division and he suggests that the causes of cerebral palsy and clumsiness are the same. The evidence for an abnormally high prevalence of perinatal complications in clumsy children, however, is almost entirely based on clinical studies, and it has been suggested here that only more severely affected children are likely to be referred for medical attention. Therefore, the reported prevalence of such complications in clinical studies may be characteristic only of more severely affected children.

Gubbay (1975b) found no significant difference between the prevalence of perinatal complications in the 56 clumsy children identified in his study and their controls. By comparison, Brenner et al. (1967) report that birth difficulties were more common in their sample of 14 clumsy children, as compared with their controls. Similarly, Johnston et al. (1987b) found a higher than normal prevalence of perinatal complications among the forty-seven 5-year-old and fifty-five 7-year-old clumsy children identified in their study. The problem with surveys is that commonly the medical history of the child is obtained by the use of questionnaires or parent interviews, and so the results are dependent on the recall of events that occurred some years previously. Consequently, the findings of such studies are subject to errors in recall.

Although there are problems with both clinical studies and surveys, it is evident that some clumsy children have a history of perinatal complications whilst others do not. Nonetheless, it is apparent that some of these children have suffered brain damage. Gubbay (1975a) compared the results of electroencephalogram (EEG) examinations of 52 clumsy children and 51 controls, and he reports finding abnormal tracings in 44% of the clumsy children, as compared with 17% of controls. Whilst this result suggests an association of clumsiness with brain damage, Gubbay (1975b) comments that the EEG can provide only a minor contribution to diagnosis. However, Knuckey et al. (1983) found that some clumsy children have a cerebral abnormality. In this study computerized axial tomography (CAT) scans were used to examine a group of 51 children who had been referred because of their difficulties with motor skills. A comparison of the scans of the clumsy children with those of 33 controls revealed abnormalities in 39% of the clumsy children, as compared with 9% of the controls. Again, however, since it is likely that only more seriously affected children will be referred for medical attention, the Knuckey et al. (1983) findings may be characteristic only of extreme cases. Nonetheless, it remains possible that some less severely affected children also have suffered brain damage that is not revealed by normal neurological examination.

Orton (1937) suggested that the absence of hand preference indicates a confusion of cerebral dominance, and Benton (1959) noted a significant frequency of problems of left-right discrimination and ambidexterity among children with an intellectual disability and brain damaged children with cerebral palsy. Also, Bakin (1977) has suggested that left-handedness is associated with mild neurological dysfunction, and Bishop (1980, 1984, 1990) has proposed that a mild brain abnormality could result in "pathological left-handedness". Further, Rasmussen, Gillberg, Waldenstrom and Svenson (1990) report finding that, although not statistically significant, left-handedness was three times more common in a group of children who were diagnosed as suffering from MBD than in a control group. Reuben and Bakwin (1968) have commented that failure to establish lateral dominance may be associated with clumsiness, and an unusually high incidence of left-handedness, ambidexterity or ambilaterality, and left-right confusion has been noted among clumsy children in a number of earlier clinical studies (e.g. Gubbay et al., 1965; Gubbay, 1975a; Walton, 1961; Walton et al., 1962; Wilson, 1974). However, the relationship between handedness and impaired motor skill is tenuous, and these early findings have not been pursued.

Not all left-handed people are clumsy and, as Bishop (1980) comments, left-handedness is only a very indirect indication of neurological abnormality. Moreover, Baker (1981) comments that shoulder girdle instability is common in clumsy children and that sometimes the instability is on the side of natural dominance. As a result, she suggests, the child may choose to use the more stable hand and thus an artificial dominance is established. Further, not all ambidextrous people are clumsy. A distinction, however, should be made between the terms ambidextrous and ambilevous. Ambidexterity refers to equal dexterity of both hands whilst the ambilevous person uses both hands with equal awkwardness (Reuben & Bakwin, 1968). Although it may be difficult to distinguish between these in young children, it is likely that observations of ambidexterity, at least in some cases, refer to these children being ambilevous. In addition, Baker (1981) has suggested that the artificial dominance, which she postulates, can result in left/right confusion. Left-handedness, ambidexterity or ambilaterality, and left-right confusion, therefore, do not necessarily indicate brain damage.

The contribution of minimal brain damage to abnormal clumsiness therefore remains uncertain. Moreover, Reuben and Bakwin (1968) comment that birth difficulties are a doubtful cause of cerebral damage, and Wilson (1974) points out that the majority of children who have a history of perinatal complications have no sequelae. Further, Gubbay (1975b) comments that children frequently recover from severe brain injury. However, Gordon (1982) has suggested that poor concentration or attention and over-activity, which are sometimes associated with clumsiness, may be symptoms of "disordered cerebral function", and Walton et al. (1962) and Walton (1963) suggest that ambidexterity or ambilaterality is strong evidence of cerebral ambilaterality and a defect in motor organization. In particular, Walton et al. (1962) suggest that the defect involves the pathways concerned with the organization of movement and with the perception of sensory stimuli.

Motor Control

A detailed discussion of theories of motor control is beyond the scope of this thesis. (For reviews see Kelso, 1982; Kelso & Clark, 1982). Broadly, these theories can be divided into input or peripheralist, and output or centralist models (see Glencross, 1977 for a review) that differ in the role attributed to sensory feedback in movement control. Input theories are exemplified by the closed-loop models of Bernstein (1967) and Adams (1971), the central feature of which is that movement is controlled by feedback. By comparison, theorists such as Keele (1968) have proposed that movement is organized and initiated by a central process and is not feedback dependent. The evidence in support of either approach as a sole explanation is not conclusive (Connolly, 1980; Glencross, 1977), and it seems clear that both the planning of movement and the use of feedback for movement control are important in the performance of motor skills.

Feedback following the completion of an action, or knowledge of results, provides information that can be used to guide subsequent attempts (Kerr, 1982). Concurrent feedback, by comparison, provides information about ongoing movement which can be used to monitor action, and as the basis for correction of discrepancies between intended and actual movement. This form of feedback is particularly important in tasks demanding combinations of spatial and/or temporal parameters (Carroll & Bandurra, 1982). The problem with closed-loop models of movement control is that processing of feedback must involve some delay. Feedback, therefore, will be out of phase with ongoing movement (Glencross, 1977), and so feedback controlled movement will lack the smoothness characteristic of open loop control, which is not feedback dependent (Connolly, 1980). Bruner (1973) suggests that initially awkward movement patterns are shaped by feedback and "modularized" or formed into subroutines. Similarly, Glencross (1977) proposes a two-stage model, combining both closed and open-loop systems. He suggests that, in the early stages of learning, movement is under executive control and is feedback dependent, but that as skill is acquired predictable sequences of action are combined into larger units that are placed under open-loop control.

There is evidence to suggest that movements of a duration of as long as 1300 ms can be programmed (Schmidt, 1982). Longer movements, however, are thought to be executed under feedback control (Klapp, 1975).

Some motor skills are comprised of a series of short, ballistic movements. Lashley (1951), for example, pointed out that the individual finger movements of a skilled pianist are too rapid to allow for feedback control. Nonetheless, there must be some monitoring of movement. Several theorists have postulated the concept of feedforward, or efference copy, which can be thought of as a stored copy of the efferent signals of a motor programme. Schmidt (1975), for example, proposes that the efference copy provides knowledge of the execution of movement. Also, the efference copy provides a frame of reference against which afferent feedback can be evaluated (Fel'dman & Latash, 1982; Schmidt, 1975), allowing for adjustments to be made during the execution of a motor programme. Feedback, therefore, is important in the control of skilled movement, particularly during the acquisition stages.

Praxis and Gnosis

Praxis can be defined as the ability to plan movements, and gnosis as the ability to integrate sensory information (Gubbay, 1975a). Apraxia, therefore, refers to the inability to motor plan, and dyspraxia to a dysfunction in this ability. Similarly, agnosia refers to an inability to perceive the significance of sensory stimuli, and dysgnosia a defect in this ability. A number of investigators have suggested that defects of both praxis and gnosis are associated with clumsiness. For example, the disorder has been described as "developmental apraxia and agnosia" (e.g., Walton et al., 1962; Gubbay, 1973), "developmental dyspraxia and dysgnosia" (Lesny, 1980b), and "perceptual-motor difficulties" (Domrath, 1968).

Gordon and McKinlay (1980) have commented that in more severely affected children there will be a marked involvement of both functions, but a disorder of one may predominate. Further, Gordon (1982) suggests that either or both functions may be involved, and Cardus and Rebollo (1969) remark that the disorder can be exclusively of either motor or perceptive origin. Lesny (1980b), however, suggests that pure dyspraxia or dysgnosia is rare and that a combination of both is much more frequent. The problem is that praxis and gnosis are interdependent in the performance of skilled movement (Gordon, 1969; Gubbay, 1973; Hulme & Lord, 1986) and, as Walton (1961) has commented, a perceptual defect will invariably result in a defect of movement. It is, therefore, difficult to separate these functions.

Clumsiness in children has sometimes been attributed specifically to a defect of praxis (e.g. Baker, 1981; Dare and Gordon, 1970; Dawdy, 1981; Gordon, 1977; Gubbay, 1989), but there is little experimental evidence in support of such an association. Van Dellen and Geuze (1988) found the reaction time of clumsy children to be longer than that of their controls when the required response was complex, suggesting a defect of motor programming. Also, Smyth (1991) found that, when the required response involved virtually no movement, there was no significant difference in reaction time between clumsy and control children, whereas when the response involved either simple or complex movement the reaction time of the clumsy group was longer than that of their controls. Again, these findings suggest that clumsy children experience difficulty with programming of movements. By comparison, although there was considerable between subject variability, Lord and Hulme (1988) observed an improvement in performance by clumsy children in a pursuit tracking task, which they concluded provided some evidence that clumsy children can develop motor programmes. The evidence for an association of clumsiness with a motor programming defect, therefore, is inconclusive.

There is, however, strong evidence associating clumsiness with a perceptual defect.

Visual Perception

The importance of vision in the control of movement is generally accepted and the effect of loss of vision is obvious, but perceptual difficulty also can be expected to affect the performance of motor skills detrimentally. For example, Smith (1962) demonstrated that delayed or displaced visual feedback disrupted drawing tasks, and Held (1965) showed that displacement of the visual field, by prismatic lenses, was detrimental to reaching and pointing movements. Not surprisingly, then, some authors have associated abnormal clumsiness with a defect of visual perception. For example, the disorder has been described as "visuo-motor disability" (Brenner et al., 1967; Dare & Gordon, 1970), or "visuomotor incoordination" (Wilson, 1974).

A number of investigators have commented on the presence of irregular choreiform movements in clumsy children (e.g., Gordon, 1969; Gubbay, 1973, 1975a; Gubbay et al., 1965), and Prechtl and Stemmer (1962) found "chorealike twitchings of the extremities" to be common. Prechtl and Stemmer comment that the muscles controlling eye movements can also be affected, "resulting in disturbances of conjugate movement and difficulty in fixation and reading" (p. 122). Similarly, Friedman (1971) suggests that reading difficulties and awkwardness in some children can be attributed to a visual defect. He postulates that, because of a difficulty of "binocular fusional fixation" vision is blurred, out of focus, or repeatedly double, which results in reading difficulty and awkwardness of movement. It is possible, then, that some instances of abnormal clumsiness could be attributable to a visual impairment. However, most clumsy children have normal vision (Baker, 1981) and, moreover, children who suffer from an identifiable visual defect would not be included in the category of abnormal clumsiness as defined here.

Alternatively, it may be that clumsy children suffer from a functional impairment of perception that is not revealed by normal testing of visual acuity. Gordon (1968) comments that some children may suffer from a specific visual defect, such as visuo-spatial disorder which can only be attributed to profound visual agnosia. Such a defect would be expected to result in difficulty with development of the concepts of size, shape, distance and spatial relationships and, as Hulme et al. (1982a) have commented, the concepts of distance and spatial relationships are important for the performance of skilled movements.

In a series of experiments, Hulme and his colleagues have found evidence for the association of a visual perceptual defect with clumsiness. Hulme et al. (1982a, 1982b) investigated the ability of clumsy children to judge the length of lines in the visual modality, finding the judgement of clumsy children to be less accurate than that of normal controls. Moreover, Hulme et al. (1982a, 1983) found substantial correlations between visual perceptual and motor abilities. Lord and Hulme (1987) also reported evidence of a visual perceptual defect in clumsy children, finding that these performed more poorly than controls on a pursuit tracking task. They suggested that the performance of the clumsy children was adversely affected by impaired use of visual feedback for movement control. The results of these studies, therefore, provide strong evidence for an association of abnormal clumsiness with a visual perceptual deficit.

Kinaesthetic Perception

Although the role of vision in the control of movement is readily apparent, that of kinaesthesis is not, and the importance of this modality is sometimes overlooked. Kinaesthesis can be defined as the awareness of body position (Kerr, 1982), and of the position and movement of parts of the body (Hulme et al., 1982a). Proprioceptors provide information in this modality that allows for the determination of the location of parts of the body in relation to other parts (Legge and Barber, 1976). Further, the vestibular system, together with proprioceptors in the muscles of the neck, provides information about the body's position relative to gravity, and of acceleration and sudden changes in direction. This system, therefore, is closely associated with the performance of motor skills (Steinberg & Rendle-Short, 1977).

Kinaesthesis may seem to be a redundant modality since, for instance, the position of a limb can also be determined by vision. Laszlo (1967b, 1968) has demonstrated that a tapping task could be learned in the absence of kinaesthesis, and Laszlo and Baker (1972) found that, in the absence of kinaesthetic information, visual cues efficiently guided performance in a letter writing task. However, deafferentation studies using animals have shown that the preclusion of kinaesthetic information results in poor motor performance. Although animals in these studies did regain motor control after a time, it has been emphasized that the normal elegance of movement was never recovered (See Bossom, 1974, and Glencross, 1977 for reviews.). Further, using the ischemic nerve block technique, Laszlo and her colleagues have shown that the absence of kinaesthetic information also impairs the performance of motor skills by humans (Laszlo, 1966, 1967a, 1968; Laszlo & Bairstow, 1971; Laszlo, Bairstow & Baker, 1979; Laszlo & Baker, 1972; Laszlo & Ward, 1978).

Although the ischemic nerve block technique has been criticized (e.g. Glencross & Oldfield, 1975; Kelso, Stelmach & Wanamaker, 1974), it is clear that sensory information is at least significantly reduced by this procedure. Moreover, the impaired performance of motor skills resulting from the absence of kinaesthetic information is also illustrated by the effect of the disease *tabes dorsalis*. In this disease the sensory pathways from the legs may be completely destroyed. In order to walk, therefore, victims of this disease must watch their feet (Sage, 1977) and they often sway and sometimes fall when vision is occluded (McCloskey, 1978).

Steinberg and Rendle-Short (1977) have demonstrated a vestibular dysfunction in a group of children whom they describe as having minor neurological impairment, but who could equally be described as being clumsy. Moreover, these investigators also noted that the children in their study had difficulty with maintaining and adjusting muscle tone. The absence of proprioceptive information would be expected to impair postural orientation and to affect muscle tone (Arnheim & Sinclair, 1975), and Baker (1981) has noted abnormal muscle tone in clumsy children, most being hypotonic, which she associates with diminished proprioception. The poor balance often noted in clumsy children (e.g., Baker, 1981; McKinlay, 1978; Orton, 1937; Williams et al., 1983) could, therefore, be attributable to a defect of kinaesthetic perception.

Smyth and Glencross (1982, 1986) found the kinaesthetic reaction time of clumsy children to be longer than that of normal controls, suggesting that clumsy children process kinaesthetic information slowly, but it is not clear from their findings that this slow rate of processing is mediated by a perceptual defect. However, suggesting such a defect, Ayres (1965) found that the "dysfunction group" in her study had difficulty with a test of perception of joint movement, and Hulme et al. (1982a) found that clumsy children were less accurate in judgments in the kinaesthetic modality of movement distance than were their controls.

Two other studies (Laszlo et al., 1988; Bairstow & Laszlo, 1989) also suggest that clumsiness is associated with a perceptual defect in the kinaesthetic modality. Laszlo and her colleagues found that the performance of clumsy children on both the Perceptual-Motor Abilities Test (PMAT), devised by Laszlo and Bairstow (1985a, 1985b) to measure kinaesthetic sensitivity, and the Stott, Moyes and Henderson (1984) Test of Motor Impairment (TOMI), improved following "kinaesthetic training". However, interpretation of the findings of these studies is problematic. The children in the Laszlo et al. (1988) and Bairstow & Laszlo (1989) studies were identified as clumsy in the first instance by class teachers and, as was pointed out in Chapter 1, teachers cannot reliably identify clumsy children. Also, the children included in the final sample were selected, from those identified by teachers, on the basis of testing with the PMAT, and not the TOMI. That is, selection was on the basis of poor kinaesthetic perception rather than motor ability, and so the children in these studies may not have been clumsy. Moreover, as will be discussed in Chapter 3, the test of kinaesthetic sensitivity developed by Laszlo and Bairstow (Bairstow & Laszlo, 1980; Laszlo & Bairstow, 1981; 1985a; 1985b), which is the basis of the PMAT, is open to criticism on a number of grounds. Another problem with these studies is that the observed improvement in performance may have been attributable to similarities between the tasks used for kinaesthetic training and those included in both the PMAT and the TOMI. In addition, vision and kinaesthesis are confounded in these studies, and it is difficult to see how the observed improvement in performance could be attributed specifically to kinaesthetic training.

Translation Between Modalities

Vision is generally accepted as being the predominant modality and, when a conflict between modalities is present, it can be expected that subjects will make judgements on the basis of vision in preference to tactile or kinaesthetic information (Hay, Pick & Ikeda, 1965; Kinney & Luria, 1970; Rock & Victor, 1964). Further, Adams, Gopher and Lintern (1977) have demonstrated that vision is the more powerful modality in motor learning. However, it is apparent that both vision and kinaesthesis play a necessary role in the performance of motor skills. Moreover, perception in the two modalities is interrelated. Held and Bauer (1974) proposed that visual guidance requires mapping the co-ordinates of a movement onto the visual space, and Smyth (1982) and Smyth and Marriott (1982) have suggested that the kinaesthetic system may be calibrated by vision. Also, movement facilitates perception. For example, Hulme (1979) found that tracing provided additional information which aided children's recognition.

Seiderman (1970) suggests that it is as a result of the combination of movement and perceptual exploration that information from the two modalities comes to have the same meaning. If this does not happen, he suggests, the child is confused by different information from the two modalities. Similarly, Swartz (1978) argues that movement is necessary for the development of a "visual-motor match". He argues that through movement visual distortions are eliminated and so the child can appreciate that the shape and size of an object do not change with distance.

Information must, then, be translated between modalities, and the mechanism for this translation has been described as an "equivalence dictionary" (Connolly & Jones, 1970), or a "cross-modal dictionary" (Bryant, 1974).

There have been inconsistent findings in studies that have investigated translation of information between modalities. (For critical discussions see Bryant, 1974; Goodnow, 1971.) Sometimes the reason for discrepant findings is not clear. For example, in both the Jones and Robinson (1973) and the Fishbein, Decker and Wilcox (1977) experiments, subjects were required to make judgements of geometric shapes. However, where Jones and Robinson found that performance within the visual modality was superior, Fishbein and his colleagues found no difference between within-modal and translation conditions. At other times, discrepant findings can be attributed to differences in experimental tasks. In the Connolly and Jones (1970) experiment subjects were required to make visual judgements of line length, or of linear distance moved with vision precluded. By comparison with the Fishbein et al. (1977) findings, accuracy of judgement in within-modal conditions was found to be superior to that in translation conditions. As Bryant (1974) has remarked, shape can only be judged on an absolute basis whereas length can be judged on a relative basis. The disparity in findings between the Connolly and Jones (1970) and Fishbein et al. (1977) studies may therefore be attributable to differences in experimental tasks. Thus, as Goodnow (1971) has commented, inconsistent findings may be attributable to differences in the nature of the information involved. The results of studies investigating the translation of information between modalities are therefore sometimes difficult to interpret.

A specific defect in the translation process has not been associated with children who are abnormally clumsy. However, a sensory integrative dysfunction has been associated with children who have learning difficulties, some of whom also exhibit awkward movement (Ayres, 1971, 1972). It is possible, then, that a dysfunction in the translation of information between modalities could be associated with abnormal clumsiness. This was investigated by Hulme and his colleagues, by having their subjects judge the length of a stimulus line in one modality and reproducing this length in the other. Hulme et al. (1982a) found that performance in tasks requiring translation between modalities was less accurate than in within-modal tasks, but this was equally so for both clumsy children and their controls. Moreover, the correlations between motor ability and performance in their two translation tasks were not statistically significant. Hulme and his colleagues, therefore, found no evidence of a specific defect of the translation process in their clumsy children. It is interesting, however, that Lord and Hulme (1987a) remark that in their investigation of visual perceptual abilities, "the clumsy children exhibited a lower degree of size constancy than the control children" (p. 255). As has been pointed out, Seiderman (1970) and, in particular Swartz (1978), argue that movement is an essential element in the development of perception and that this results in a visual-motor match which, among other things, results in the development of size constancy. Therefore, the Lord and Hulme (1987a) comment suggests the possibility of a defect in the translation process among clumsy children.

Perceptual Development

When a translation between modalities is required, error can result from either within-modal perceptual or translation defects. Consequently, as Bryant (1974) has pointed out, in experiments investigating the translation of information between modalities within-modal effects must be distinguished from translation effects.

Birch and Lefford (1967) used a task involving geometric form recognition to investigate the ability of 5 to 11 year old children to translate visual and kinaesthetic information between modalities, and found that performance improved with increase in age. However, as Bryant (1974) points out, Birch and Lefford did not include within-modal tasks as controls, and so the improvement they observed could be attributable to the development of within-modal perception, rather than of the translation process. Similarly, Connolly and Jones (1970) investigated the ability of their subjects to translate length information between modalities and found that, as in their within-modal tasks, performance improved with age. Again, however, Connolly and Jones did not examine a differential improvement with age between translation and within-modal performance. Nonetheless, as Bryant (1974) points out, their data do strongly suggest that the translation process improved more than did within-modal performance between the ages of 5 and 8 years, and he comments that it may be that, for judgements of length, children's ability to translate information between modalities lags behind their ability to make within-modal judgements. Further, Jackson (1973) investigated the translation of form information between modalities and found greater improvement in accuracy with age in within-modal, as compared with translation tasks, suggesting a differential development between perceptual and translation abilities. By comparison, using an experimental design following that of Connolly and Jones (1970), although Hulme et al. (1983) found the translation performance of 10-year-old children to be superior to that of 6-year-olds, they found no differential improvement in translation, as compared with within-modal tasks. Although, then, it seems that the ability to translate information between modalities develops with age during childhood, findings for a differential improvement with age in within-modal perception, as compared with translation are equivocal.

On the other hand, the findings of several studies suggest that perception, in both the visual and kinaesthetic modalities, develops during childhood. Connolly and Jones (1970) used a line length reproduction task to investigate the visual and kinaesthetic perceptual abilities of children aged 5 to 11 years and adults, and found that performance improved with age. Again, using the same experimental design, Hulme et al. (1983) similarly found the performance of 10-year-old children to be superior to that of 6-year-olds, in both the visual and kinaesthetic modalities. Further, using a match-to-sample procedure, Jackson (1973) found a linear relationship between age and accuracy in judgement of shape in the kinaesthetic modality, for children aged 6 to 10 years. More recently, while developing their test of kinaesthetic sensitivity, Laszlo and Bairstow (1980) and Bairstow and Laszlo (1981) investigated the kinaesthetic perception of a sample of 475 children aged from 5 to 12 years. Although they observed considerable individual differences, Laszlo and Bairstow also report that performance improved with age.

Hulme et al. (1984) found that there was no significant difference between 10-year-old clumsy children and 6-year-old control children of similar motor ability, in either judgements of line length in the visual and kinaesthetic modalities, or in the translation of length information between modalities. Further, they found no differential effect between groups for within-modal, as compared with translation judgements. These findings suggest that the perceptual, and hence the translation ability, of clumsy children is comparable to that of younger children who are not clumsy. This suggests that clumsiness in children is associated with a perceptual defect which affects both modalities.

The findings of a number of studies, which have been discussed, suggest that some clumsy children may have suffered brain damage, and Frostig (1963) has commented that brain damage is a major cause of perceptual disabilities in children. It is possible, therefore, that in some cases clumsiness could be attributed to a functional defect of the perceptual process arising from brain injury. In other cases, however, there is no history of perinatal complications and no apparent evidence of brain damage. Nonetheless, it is possible that in these children also, clumsiness is attributable to a perceptual difficulty. Due to normal variation in rate of development, it is possible that in some children the perceptual and translation processes have not yet fully developed. Alternatively, it may be that in some individuals, again due to normal variation, these processes do not function at a normal level of efficiency. In summary then, abnormal clumsiness could result from a functional defect of the perceptual and/or translation processes, which may be attributable to either brain damage or normal variation.

CHAPTER 3
RESEARCH APPROACH

The findings of the experimental studies discussed in Chapter 2 suggest that abnormal clumsiness is associated with a perceptual defect in the visual, and possibly the kinaesthetic modality. Also, although not conclusive, there is some support for the possible involvement of a defect in the translation of information between modalities. An investigation of the cause of clumsiness, therefore, should assess perceptual ability in both modalities, and the translation process.

Assessment of Perception

A number of tests of visual perception are available and Lord and Hulme (1987a) used a battery of such tests to investigate the visual perceptual ability of clumsy children. Assessment of perceptual ability in the kinaesthetic modality, however, is more difficult; clinical assessment is imprecise, and there is no generally accepted test of perception in this modality. Although Laszlo and Bairstow (Bairstow & Laszlo, 1980; Laszlo & Bairstow, 1981, 1985a, 1985b) have developed a kinaesthetic sensitivity test (KST), this test has been criticized on a number of grounds.

The KST, which is described in detail by Laszlo and Bairstow (1985a, 1985b) is comprised of two parts which are designed to measure kinaesthetic acuity, and kinaesthetic perception and memory. In the first part of the test the child's ability to discriminate limb position is assessed. The examiner simultaneously moves the child's hands up and then down two runways in a masking box, and the child's task is to determine which hand moved higher. In the second part the child holds a stylus in a groove cut in a perspex disc which is placed in the masking box. The examiner guides the child's hand around the pattern formed by the groove, after which the disc is rotated and the masking box is removed. The child is then asked to reposition the disc so that the pattern is in its original orientation. For the first part of the test the child's performance is scored on the number of correct discriminations, and for the second part as a mean error in degrees.

Doyle, Elliott and Connolly (1986) have criticized the first part of the KST. When developing their test, Laszlo and Bairstow used the method of constant stimuli to determine the threshold for detection of difference in arm position. As Doyle and his colleagues point out, this procedure requires that an adequate range of stimulus values be used so as to "bracket" the threshold value, and that a sufficient number of trials be used to give reliable data. Doyle and his colleagues argue that Bairstow and Laszlo (1980) and Laszlo and Bairstow (1981) used both an inadequate range of stimulus values and an insufficient number of trials at each value, casting doubt on the results of these studies.

In response to this criticism, Bairstow and Laszlo (1986) argue that a compromise was necessary since the number of trials had to be restricted because of the limited attention span of young children. In their 1980 study they found that the number of trials (60 trials, 20 at each of 1^{o}, 3^{o} and 5^{o} stimulus values) proved to be excessive; children who found the task easy complained of boredom and others, who found the task difficult, complained of being tired. Consequently, in their 1981 study the number of trials was reduced to 32 (16 at each of 4^{o} and 7^{o} stimulus values for 5 and 6-year-olds, and 16 at each of 3^{o} and 5^{o} stimulus values for older children). Further, Laszlo and Bairstow point out that in the final version of their test threshold values are not calculated, assessment being based on the number of correct responses. Using this design, they comment that "broad band discriminations can be made between the performance of individual subjects." (p. 193). However, the use of only two stimulus values does not allow for fine discrimination of kinaesthetic acuity.

The second part of the KST was not examined by Doyle and his colleagues, but as Lord and Hulme (1987b) comment, interpretation of results from this part of the test is problematic, because the task requires not only kinaesthetic perception, but also visual perception, the translation of information between modalities, and memory. Consequently, poor performance could be attributed to a defect in any one, or more of these processes. In fact, Jackson (1973) earlier used a virtually identical approach, but with a match-to-sample design, to investigate the translation of information between modalities.

Lord and Hulme (1987b) investigated the performance of the KST, using a sample of 19 children who had been clinically identified as clumsy and a matched sample of control children. All of the children were tested on a battery of four tests of motor ability, the KST and a writing test. The clumsy children were found to perform more poorly on all four motor ability tests than did their controls, but although the average KST performance of clumsy children was below that of the control children, the between-group difference was not statistically significant. Lord and Hulme also found that, for the clumsy group, performance on the first part of the test correlated with performance on three of the motor tests at a moderate to substantial level, but for the second part all correlations were very low. Further, they found that, for the clumsy group there was a substantial correlation with handwriting for the first part of the test, but not for the second. Again, these findings question the validity of the KST. On the basis of the results of their study, Lord and Hulme concluded that the KST is unsuitable for use either in research or for clinical purposes.

Hulme et al. (1982a, 1983, 1984) investigated the cause of abnormal clumsiness in children using an experimental design virtually identical to that used earlier by Connolly and Jones (1970) to investigate the relationship between visual and kinaesthetic perceptual processes, and of the translation of information between modalities. Since this design allows for a comparable assessment of perceptual ability in both modalities, the approach adopted by Hulme and his colleagues is the most valuable yet used for an investigation of the possible contribution to clumsiness of a perceptual defect. Moreover, Connolly and Jones developed a model of the translation of information between modalities, and this would seem to provide a useful framework within which to investigate this process. However, there are potential problems with the Connolly and Jones experimental design, and their model of the translation process is open to question.

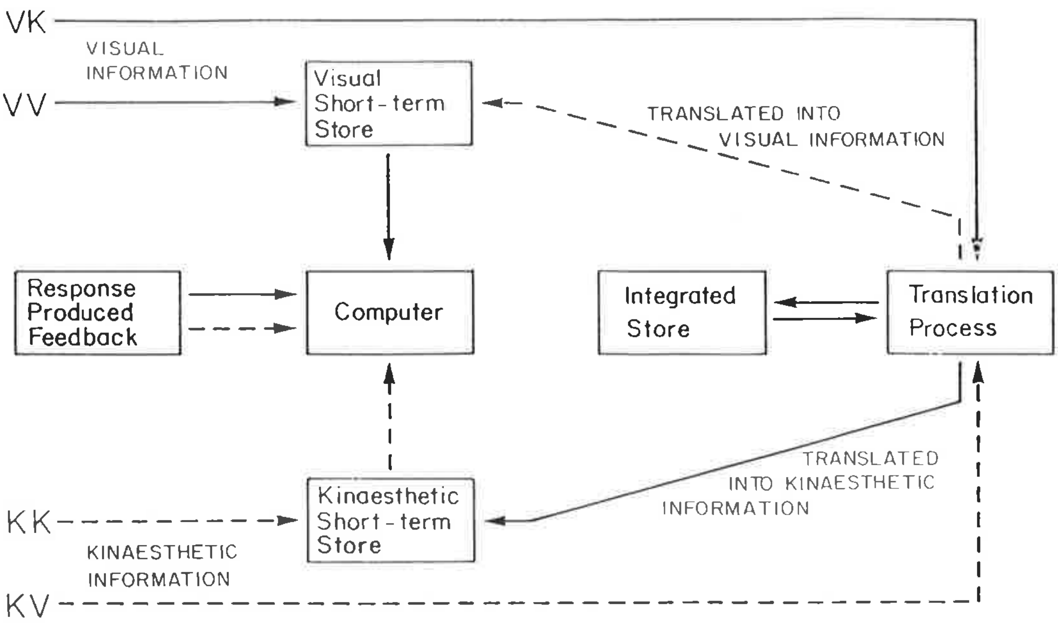
The Connolly and Jones Model

In their experiment, Connolly and Jones (1970) used within-modal and translation tasks requiring subjects to reproduce, as accurately as possible, one of five standard stimulus line lengths. In the visual modality a white standard stimulus line was presented for approximately 5 seconds in an aperture in a black perspex box. Following this presentation, a silver steel measuring tape was extended in the aperture of a similar box, placed on top of the first, until the subject was satisfied that it was the same length as the standard stimulus and instructed the experimenter to stop. In the kinaesthetic modality the length of the standard stimulus line was presented by instructing the subject to draw a line with a pencil in a slot until a stop was reached. The stop was then removed and the subject was required to reproduce the length of the movement in the same manner. During both presentation and reproduction in this modality, vision of hand movements was precluded.

Connolly and Jones tested children aged 5, 8 and 11 years, and a group of adults in these tasks. They found that performance in all conditions improved with age and that within-modal performance was superior to translation performance in all age groups. Further, although there was no significant difference in reproduction accuracy between within-modal visual (VV) and kinaesthetic (KK) conditions, performance in the kinaesthetic to visual (KV) condition was more accurate than that in the visual to kinaesthetic (VK) condition. On the basis of these results, Connolly and Jones developed an information processing model, a modified diagrammatic representation of which is shown in Figure 3.1.

According to this model, for within-modal visual tasks, information obtained from the standard stimulus is held in a visual short-term store, and the "computer" compares response produced feedback in this modality with the stimulus information held in the short-term store. The computer then issues appropriate commands to the effectors controlling reproduction. Similarly, for within-modal kinaesthetic tasks, information obtained from the standard stimulus is held in a kinaesthetic short-term store, response produced feedback in the kinaesthetic modality is compared with this information, and the computer issues appropriate commands to the effectors.

In translation tasks, by comparison, Connolly and Jones propose that information is translated between modalities *before* being placed in short-



<u>FIGURE 3.1:</u> **A modified diagrammatic representation of the Connolly and Jones (1970) model**

term store. For a kinaesthetic to visual (KV) translation, therefore, kinaesthetic stimulus information is first translated into visual information which is then held in the visual short-term store. Response produced feedback in the visual modality is then compared with the stimulus information held in the visual short-term store. Similarly, for a visual to kinaesthetic (VK) translation, visual stimulus information is translated into kinaesthetic information which is held in the kinaesthetic short-term store, and response produced feedback in the kinaesthetic modality is compared with this information. Further, Connolly and Jones postulate that translation is mediated by information held in an "integrated store", which can be thought of as an "equivalence dictionary", holding representations of relationships between information in the visual and kinaesthetic modalities.

Connolly and Jones suggest that the improvement in accuracy with age, which they observed for within-modal reproduction, can be attributed to either improvement in the short-term storage system or increased efficiency of the computer. They also suggest that the improved accuracy with age in their translation tasks can be attributed, in part, to the development of more veridical representations of relationships between the two modalities, resulting from experience with error-correcting. In addition, Connolly and Jones propose that translation of information between modalities is associated with a loss of accuracy, accounting for the superior accuracy observed in their within-modal tasks.

The "most original feature" of their results, Connolly and Jones remark, is the finding of superior accuracy in their KV as compared with their VK task. They attribute this asymmetry between translation tasks to differences in short-term stores. Based on Posner's (1967) findings, they suggest that the kinaesthetic short-term store is less efficient than the visual short-term store, because information held in the kinaesthetic short-term store is subject to temporal decay, whereas information in the visual short-term store is not. Since according to their model information in the VK condition is held in the kinaesthetic short-term store, some information is lost due to temporal decay during the storage period and a loss of reproduction accuracy results. By comparison, in the KV condition information is held in the visual short-term store where there is no comparable loss. Consequently, reproduction error is greater in the VK task.

Inconsistent Findings

A problem with the Connolly and Jones (1970) model is that, if the asymmetry observed between their translation tasks is attributable to the decay of information held in the kinaesthetic short-term store, then a similar asymmetry should have been found between their within-modal conditions. However, they report no significant difference in accuracy between the VV and KK tasks. In addition, Marteniuk and Rodney (1979) imposed a delay of 20 seconds between presentation of stimulus and reproduction, and found a similar decrement in performance between their delay and a no-delay condition. As these investigators pointed out, if loss of accuracy is attributable to temporal decay an interaction would have resulted. A further problem is that findings of asymmetry between the VK and KV conditions have been inconsistent. For example, while Jones and Connolly (1970) and Friedes (1975) found the same asymmetry as did Connolly and Jones (1970), Jones (1973) and Hulme et al. (1982a, 1983, 1984) found no asymmetry. Also, although Millar (1972) found superiority of performance in the KV condition for a group of 4-year-old children, she also found asymmetry in groups of 6 and 8-year-olds which was in the opposite direction; i.e. performance was more accurate in the VK condition. These results cast doubt on the validity of the Connolly and Jones (1970) explanation for superior accuracy in the KV than in the VK condition.

Vision of the Surround

In experiments similar to that of Connolly and Jones (1970), Marteniuk and Rodney (1979) used luminescent green lines and Newell et al. (1979) used two small lights, one at each end of the line, to present standard stimuli in the visual modality. In both experiments, when subjects were tested in darkness no difference in accuracy was found between VK and KV conditions. By comparison, when the experimental room was illuminated, in both experiments superior accuracy was found in the KV condition, i.e. the same asymmetry as observed by Connolly and Jones (1970). These results indicate that asymmetry between translation conditions is associated with availability of vision of the surround.

Newell et al. (1979) suggest that, although subjects cannot see their arms during presentation of the standard stimulus length in the kinaesthetic modality, in addition to kinaesthetic information they can use visual cues to facilitate subsequent reproduction. When the standard stimulus is presented in the kinaesthetic modality subjects can judge the location of the end-point of the movement using kinaesthetic information, and relate this location to visual cues in the surround. The standard stimulus can then be reproduced in the visual modality using this information to locate the end-point of the line, so enhancing accuracy in the KV condition. However, if subjects can relate visual cues to arm position during presentation in the kinaesthetic modality, and use these cues to facilitate subsequent reproduction in the visual modality, it would be expected that the reverse also should be true. That is, subjects should be able to relate visual cues to the end-point of a stimulus line presented in the visual modality and use these cues to facilitate reproduction in the kinaesthetic modality. This would result in enhanced accuracy in the VK condition, in the same manner as in the KV condition, and so no asymmetry would be expected. An explanation of asymmetry based on the use of visual cues in the surround, therefore, depends upon subjects using visual cues to facilitate reproduction of the standard stimulus in the kinaesthetic, but not the visual modality.

Strategies

When instructed to reproduce the length of a standard stimulus, it can be expected that subjects will try to comply with the experimenter's instructions. That is, they will attempt to reproduce the length of a standard stimulus line or movement distance. This can be described as a "distance" strategy. However, it can also be expected that subjects will use any available information or strategy to facilitate their task. For example, it has already been suggested that subjects can use visual cues in the surround as an aid to reproduction. In particular, it has been suggested that subjects can reproduce a line which ends at the same location as does the standard stimulus. This can be referred to as a "location" strategy. Providing that the start points of the presentation and reproduction lengths are aligned, and that the end-point is accurately located, this strategy will result in an accurate reproduction.

Commonly, in tasks of this nature the standard stimulus is presented in the visual modality using lines. For example, Connolly and Jones (1970) used a white line and Salmoni and Sullivan (1976) used a line of luminous paint. As Diewert and Stelmach (1977) have pointed out, this results in the presentation of both distance and location information, i.e. the length of the line and the location of its end-point. Therefore, if the start-points of the standard stimulus and reproduction lines are aligned, the subject can adopt either a distance or a location strategy. Presuming that subjects follow the experimenter's instructions to reproduce the length of the standard stimulus, they will use a distance strategy. However, there is no control over strategy, and either a distance or a location strategy can be used.

In the kinaesthetic modality, by comparison, the length of the standard stimulus line is presented by having the subject move his or her hand over a specified distance. For example, in the Connolly and Jones (1970) experiment subjects drew a line in a slot until a stop was reached. Salmoni and Sullivan (1976) comment, however, that presentation of distance in this way is invalid. As they point out, there is no evidence of a pure kinaesthetic distance receptor. Similarly, Diewert and Stelmach (1977) remark that this method of presentation provides only information about changes in location. While it is possible for subjects to judge movement distance between the start and end-points of the movement, this requires judging the location of both points and retaining this information in memory while judging the movement length. By comparison, a location strategy requires only identifying the end-point of the movement. When the standard stimulus is presented in the kinaesthetic modality, therefore, it is likely that subjects will use a location strategy.

Suitability of modality to strategy is also likely to influence choice of strategy. Both vision and kinaesthesis are equally suited to judgements of location (Salmoni and Sullivan, 1976). By comparison, kinaesthesis is not suitable for accurate judgements of movement distance. Hermelin and O'Connor (1975) tested the ability of congenitally blind and blindfolded subjects to reproduce line lengths and locations in the kinaesthetic modality. Subjects were instructed to use either a distance or a location strategy. To ensure that in the distance strategy condition subjects reproduced the length of the standard stimulus movement, the start point of the reproduction line was randomly varied, and it was explained to subjects that the location of the end point of movement was an unreliable cue. Hermelin and O'Connor found superior accuracy in their location condition, showing that kinaesthesis is more suited to judgements of location than distance. Using a similar experimental design, Salmoni and Sullivan (1976) tested the ability of sighted subjects to reproduce either the length, or the end-point of visually and kinaesthetically presented lines. Salmoni and Sullivan found that, in their distance conditions, error was greater in the kinaesthetic than the visual modality, showing that vision is more suited to judgements of length than is kinaesthesis. Therefore, when the standard stimulus is presented in the visual modality, the suitability of vision for judgements of both distance and location allows for the use of either strategy. However, when the standard stimulus is presented in the kinaesthetic modality, the unsuitability of this modality for accurate judgements of movement distance is likely to result in subjects using a location strategy.

A further factor influencing choice of strategy is the frame of reference available. When the experimental room is illuminated a visual frame of reference is available. As already pointed out, Newell et al. (1979) have suggested that visual cues in the surround can be used as an aid, and clearly such cues can facilitate reproduction when a location strategy is used. However, a visual frame of reference is also important when judging the length of a visually presented standard stimulus line. When making such a judgement, the distance of the standard stimulus from the observer is a relevant factor. Also, subjects may be able to judge the length of the standard stimulus in relation to the width of some object or other reference.

By comparison, when a visual frame of reference is precluded, by testing subjects in darkness, judgements of the length of the standard stimulus line will be difficult. However, a kinaesthetic frame of reference, based on the subjects' awareness of their bodies, will always be present. Consequently, when a visual frame of reference is not available subjects can only make judgements of standard stimuli using their kinaesthetic frame of reference. Moreover, since kinaesthesis is suitable for judgements of location, but not of movement distance, it can be expected that judgements of standard stimuli will be based on location, rather than distance information. Therefore, when a visual frame of reference is precluded, subjects can be expected to use a location strategy.

In summary, then, although subjects are instructed to reproduce the length of a standard stimulus, when the standard stimulus and reproduction lines are aligned the strategy used will be influenced by availability of information in the standard stimulus, suitability of modality to strategy, and the frame of reference available. The influence of these factors is summarized in Table 3.1. This Table shows that, when the standard stimulus is presented as a line in the visual modality and a visual frame of reference is available, subjects can use either a distance or a location strategy. However, when a visual frame of reference is precluded, because of the resultant difficulty in judgement of the length of the standard stimulus, subjects would be expected to use a location strategy. Further, when the standard stimulus is presented in the kinaesthetic modality, because of the unsuitability of kinaesthesis for accurate judgement of movement distance, subjects can be expected to use a location strategy, regardless of the availability of a visual frame of reference.

Table 3.1

Factors Influencing Strategy Use in Reproduction of a Standard Stimulus Line

Information Available	Strategy Suitable	Visual Frame of Reference	Judgement of Length	Strategy Used
Visual Presentation				
Distance and Location	Distance or Location	Available	Possible	Distance or Location
Distance and Location	Distance or Location	Precluded	Difficult	Location
Kinaesthetic Presentation				
Location	Location	Available	Difficult	Location
Location	Location	Precluded	Difficult	Location

Strategy Effect

Although, then, in experiments following the Connolly and Jones (1970) design subjects are instructed to reproduce the length of the standard stimulus, when strategy is not controlled either a distance or a location strategy can be used. Moreover, differences in strategy, together with suitability of modality to strategy, provide an alternative explanation of asymmetry between translation conditions to that suggested by Connolly and Jones.

When the standard stimulus is presented as a line in the visual modality, and a visual frame of reference is available, subjects can comply with the experimenter's instructions to reproduce the length of the standard stimulus, and so use a distance strategy. However, when the visual standard stimulus is reproduced in the kinaesthetic modality, because kinaesthesis is not suitable for accurate judgements of movement distance a loss of accuracy will result. On the other hand, when the standard stimulus is presented in the kinaesthetic modality subjects can be expected to use a location strategy and, since both modalities are suitable for judgements of location, when the kinaesthetic standard stimulus is reproduced in the visual modality there will be no comparable loss of accuracy. Therefore, if as would be expected, subjects use a distance strategy in the VK condition, but a location strategy in the KV condition, superior accuracy will be found in the KV condition, i.e. the asymmetry observed by Connolly and Jones (1970). By comparison, when a visual frame of reference is precluded subjects can be expected to use a location strategy in both the VK and KV conditions. In this case, since both modalities are suitable for judgements of location, there will be no loss of accuracy in either conditions, and so no asymmetry will be found.

For within-modal visual (VV) and kinaesthetic (KK) reproduction, it can be expected that the use of strategy will be similarly influenced. Again, when a visual frame of reference is available subjects can use a distance strategy in the VV condition, but it can be expected that they will use a location strategy in the KK condition. In this case, however, since vision is suitable for judgements of distance, and kinaesthesis is suitable for judgements of location, there will be no loss of accuracy due to unsuitability of modality to strategy in either condition. Similarly, if subjects use a location strategy in both conditions, since both modalities are suitable for judgements of location there will be no loss of accuracy in either condition. Alternatively, it is possible for subjects to use a distance strategy in both the VV and KK conditions. However, because of the difficulty associated with judgement of both the standard stimulus and reproduction movement distances, it would seem to be unlikely that subjects would use a distance strategy in the KK condition unless forced to do so. Consequently, it is improbable that a distance strategy would be used in both within-modal conditions. An asymmetry would not be expected to be found, therefore, between within-modal conditions.

The present explanation, then, accounts for the finding by Connolly and Jones (1970) of an asymmetry between translation conditions, but not between within-modal conditions. Moreover, this explanation also accounts for the reported absence of asymmetry when a visual frame of reference is precluded. The weakness in the explanation is that it rests on the assumption that subjects will comply with the experimenter's instructions to use a distance strategy in the VK condition. Since it would be expected that a location strategy would be easier to use and that subjects will use any strategy to facilitate their task, it is not clear why subjects would use a distance strategy. Nonetheless, it is possible that in some instances subjects do comply with the experimenter's instructions, but that in others they do not. This would account for the reported inconsistent findings of asymmetry between translation conditions when vision of the surround is available.

In experiments following the Connolly and Jones (1970) design, therefore, when not controlled strategy can result in differences in accuracy between conditions. Further, differences in strategy can also affect the pattern of error. Salmoni and Sullivan (1976) instructed their subjects to use either a distance or a location strategy, and they forced their subjects to use a distance strategy by randomly varying the start-point for the reproduction line. Error was found to increase with line length in distance conditions, but not in location conditions. In other words, the pattern of error differed between strategies.

It is generally accepted that judgements of line length are influenced by perceptual factors. For example, the Müller-Lyer and Ponzo illusions are well known. Contextual effects, therefore, can be expected to result in either an overestimation or an underestimation of line length. The resulting error is commonly referred to as constant error, since its effect remains constant over trials, but this error can be expected to vary with both contextual effect and the magnitude of the stimulus. In addition, reproduction of the length of a stimulus line will be affected by a variable error, i.e. overestimation or underestimation due to uncertainty. This error is related to the magnitude of the stimulus, and the relationship has been variously expressed in the well known Weber's, Fechner's and Stephen's laws. (For a review see Kaufman, 1974.). The increase in error with line length observed by Salmoni and Sullivan (1976), therefore, can be attributed to these effects. By comparison, when a location strategy is used these effects will not be present and, consistent with this, Salmoni and Sullivan found that in their location conditions error did not increase with the length of the standard stimulus. Therefore, since it has been argued that in experiments following the Connolly and Jones (1970) design subjects can use either a distance or a location strategy, variations in strategy can result in differences in error patterns.

Error Measurement

A further problem with experiments of this design is that the measure of error used can affect the results. Absolute (i.e. mean unsigned) error has commonly been used as a measure of accuracy of performance and sometimes algebraic (i.e. mean signed) error has also been used. Algebraic error has often been described as constant error or bias, since it reflects a trend to either positive or negative error, e.g. a length which is either too long or too short. Therefore, the use of absolute error is understandable since it would be expected to give a bias-free measure of performance. In addition, variable error (i.e. mean within-subject variability) has also sometimes been used. Again, since variable error gives a measure of the subject's consistency of responding, the use of this measure is understandable.

A number of investigators, however, have questioned both the use of absolute error and the relationships between absolute error (AE), algebraic or constant error (CE) and variable error (VE) (Schutz & Roy, 1973). When error scores are normally distributed the form of the distribution is determined by the mean and the variance, and Schutz and Roy have shown that AE is a function of CE and VE. In contrast, if the scores are severely skewed, as Schutz and Roy point out, the relationship between AE, CE and VE is difficult to determine.

If all of the error scores are of the same sign AE must equal CE, but if there is only a trend towards either positive or negative scores the two measures are not equal. By comparison, if positive and negative scores are equally distributed AE will provide an equivalent measure to VE. Using data from other studies and computer generated data, Schutz and Roy (1973) examined the correlations between AE, CE and VE. When the majority of scores were of the same sign substantial correlations were found between AE and CE and, when the scores were equally distributed with regard to sign and the mean CE was close to zero, substantial correlations were found between AE and VE. On the basis of these findings Schutz and Roy concluded that, when the mean CE differs from zero by more than about one standard deviation, AE and CE are measures of the same characteristic of the distribution and that, when CE is approximately zero, both AE and VE are measures of variability.

Obviously, the relationships between AE and CE will vary with the proportion of scores which are of the same sign. For example, Schutz and Roy found that, when 2.5% of the scores were negative the correlation between AE and CE was .99, whereas when two-thirds of the scores were of one sign the correlation was approximately .50. Similarly, the relationship between AE and VE depends upon the scores being normally distributed and the proportion of positive and negative scores being equal. Therefore, assuming that the scores are normally distributed, when the criteria suggested by Schutz and Roy (i.e. mean CE differing from zero by more than about one standard deviation, or the mean CE being close to zero) are met, AE can be taken only as providing a close estimate of either CE or VE, respectively. Nonetheless, it is clear that AE is influenced by CE and VE. Schutz and Roy conclude that AE is a redundant measure and so it should not be used.

Investigators who have adopted an experimental design similar to that of Connolly and Jones (1970) have commonly used AE as a measure of performance (e.g., Diewert and Stelmach, 1977; Hulme et al., 1982a, 1982b, 1983, 1984; Jones, 1973; Jones and Connolly, 1970; Marteniuk and Rodney, 1979; Millar, 1972; Newell et al., 1979; Salmoni and Sullivan, 1976). In a minority of cases CE (e.g., Marteniuk and Rodney, 1979; Newell et al., 1979; Salmoni and Sullivan, 1976), or VE (e.g., Connolly and Jones, 1970; Hulme et al., 1982a) has also been analyzed. Thus, Schutz and Roy's conclusion not withstanding, the use of AE as a measure of performance allows for comparison between studies. Salmoni and Sullivan

(1976), for example, comment that their analyses focused on AE to allow for comparison with the findings of Connolly and Jones (1970). However, since Schutz and Roy (1973) have shown that AE is a function of CE and VE, and that the relationship between AE and CE varies with the proportion of scores which are of one sign, the interpretation of an analysis using AE is open to question.

The slope of the regression of length reproduced, on the standard stimulus line length, provides an alternative measure of performance. This form of error was used by Hermelin and O'Connor (1975) to compare performance between groups, but not to examine performance within or between conditions. However, the slope of the regression line can be expected to be affected by the perceptual bias associated with contextual factors and, as has been discussed, this effect can be expected to result in either an overestimation or an underestimation of line length and to be related to the magnitude of the standard stimulus. Consequently, contextual effects will be reflected in the slope of the regression line. Moreover, although contextual factors will always be present, their effects can be expected to vary between experimental conditions and to be difficult, if not impossible to determine. Contextual factors, therefore, introduce a confounding variable, and so comparisons using the regression of length reproduced on stimulus length as a measure of performance are likely to be questionable.

In addition to the effect of contextual bias, as has been pointed out, reproduction of a stimulus line length will be affected by a variable error, i.e. overestimation or underestimation due to uncertainty, and this error is related to the magnitude of the stimulus. A measure of this variable error is provided by residual error, i.e. the mean unsigned deviation in length reproduced about the regression line. Consequently, residual error provides a measure of accuracy which is related to stimulus magnitude, *after removing bias attributable to contextual effects*. It remains that residual error will be related to the length of the standard stimulus when a distance strategy is used, but not when a location strategy is used. However, when strategy is controlled residual error will provide a bias-free measure of performance that, in tasks requiring the reproduction of a standard stimulus, is more appropriate than either absolute or algebraic error.

CHAPTER 4

STRATEGIES IN TRANSLATION BETWEEN MODALITIES

In Chapter 3 it was argued that, in experiments following the Connolly and Jones (1970) design, subjects can reproduce either the length of the standard stimulus (a "distance" strategy), or alternatively a line ending at the same location as the standard stimulus (a "location" strategy). Judgements of length are more difficult than judgements of location, and so subjects would be expected to prefer to use a location strategy. However, it was also argued in Chapter 3 that, when the standard stimulus is presented in the visual modality, because distance information is available, subjects can comply with the experimenter's instructions and so will use a distance strategy. On the other hand, it was argued that when the standard stimulus is presented in the kinaesthetic modality, because only location information is available subjects are likely to use a location strategy. Further, it was argued that when a visual frame of reference is not available, judgements of distance are difficult, and so when vision of the surround is precluded subjects would be expected to use a location strategy.

Hermelin and O'Connor (1975) and Salmoni and Sullivan (1976) have demonstrated that distance and location strategies are associated with different error patterns. Moreover, it was argued in Chapter 3 that accuracy of reproduction can be affected by the suitability of modality to strategy. Therefore, if the modality of the standard stimulus and the availability of vision of the surround influence the subject's choice of strategy as suggested, differences in performance between experimental conditions may be attributable to the use of different strategies. This is particularly relevant to comparisons between experimental conditions in which subjects are required to translate information between modalities. As was discussed in Chapter 3, Connolly and Jones (1970) and several other investigators observed an asymmetry between accuracy in translation conditions, but in other studies no asymmetry was found. This inconsistency in findings could be attributable to differences in strategy use.

EXPERIMENT 1

This experiment was conducted to test the hypotheses that the modality of presentation of the standard stimulus, and the availability of vision of the surround, will influence the strategy adopted by subjects in tasks requiring the reproduction of a line of given length, and in which information must be translated between modalities. It was predicted that subjects would use a distance strategy only when the standard stimulus was presented in the visual modality and vision of the surround was available; when the standard stimulus was presented in the kinaesthetic modality, or when vision of the surround was precluded, it was predicted that a location strategy would be used.

Both Hermelin and O'Connor (1975) and Salmoni and Sullivan (1976) found that absolute error increased with the length of the standard stimulus in their distance conditions, but that this did not occur in their location conditions. On the basis of these two studies, therefore, the predicted use of strategy can be tested using the pattern of absolute error. However, the use of absolute error was questioned in Chapter 3, and residual error was proposed as an alternative measure of performance. It was argued that residual error would be related to the length of the standard stimulus when a distance strategy is used, but not when a location strategy is used, and so residual error can similarly be used to determine strategies used.

Method

Subjects

Twelve first year university students (five female and seven male) were used as subjects. All subjects were right hand dominant.

Experimental Tasks and Apparatus

Subjects were presented with stimuli comprising lines of different lengths ("standard" stimuli), which they were required to reproduce as accurately as possible. Stimulus lines were presented in the visual modality and reproduced in the kinaesthetic modality (VK), or presented in the kinaesthetic modality and reproduced in the visual modality (KV), with vision of the surround either available (A) or precluded (P). This resulted in four experimental conditions: VKA, VKP, KVA and KVP.

Figures 4.1 to 4.3 show the apparatus used in this experiment and a detailed description is provided in Appendix 4.1. The main items of equipment were a video monitor, a screening box with a 12cm diameter viewing aperture, a handle which moved smoothly and with a low level of friction on a track, a joy-stick and a personal computer (PC). The PC was used to control the presentation of standard stimuli, to present auditory signals, and to record subjects' responses. To prevent reflections, the monitor screen was covered with black voile material.

In the visual modality the stimulus line was presented on the monitor screen for three seconds. Reproduction of line length in this modality was controlled by the joy-stick. When the joy-stick was held to the right a line was

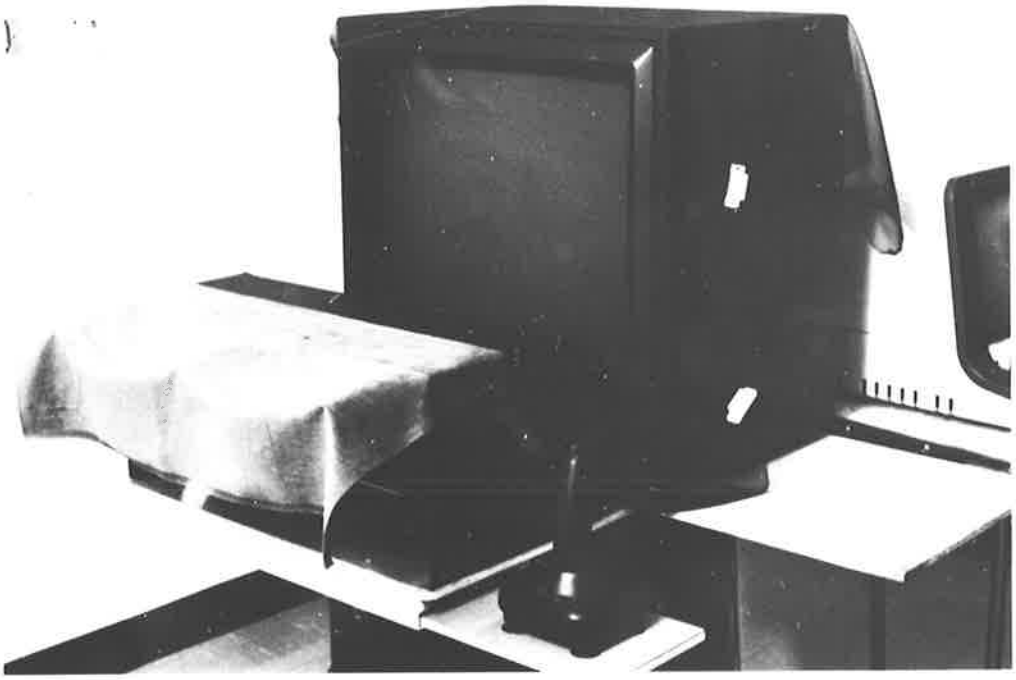


FIGURE 4.1: Apparatus used in Experiment 1 - Vision available conditions

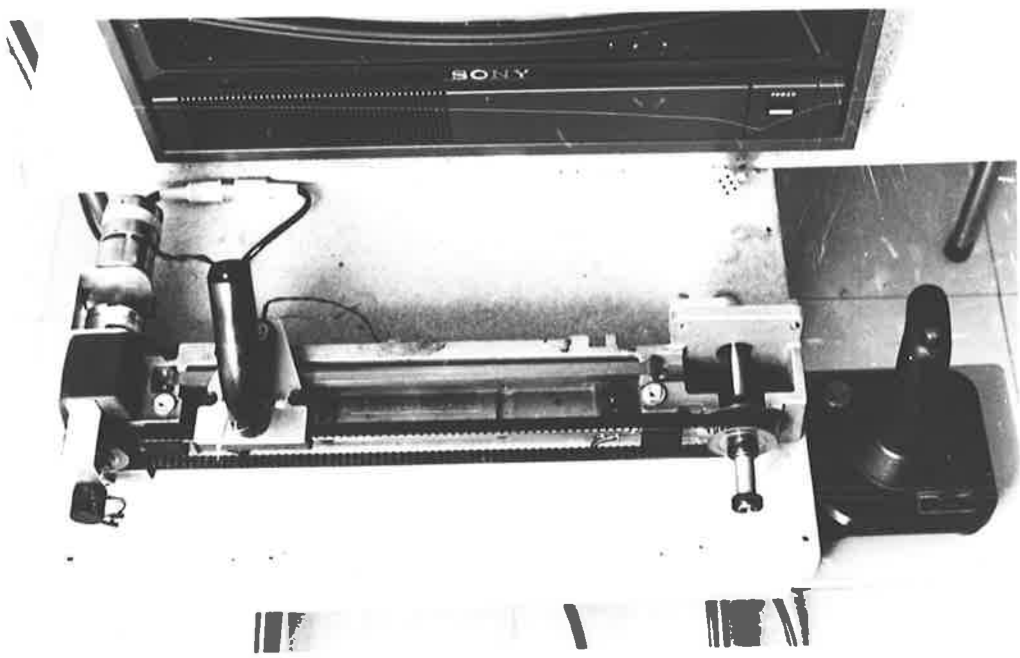
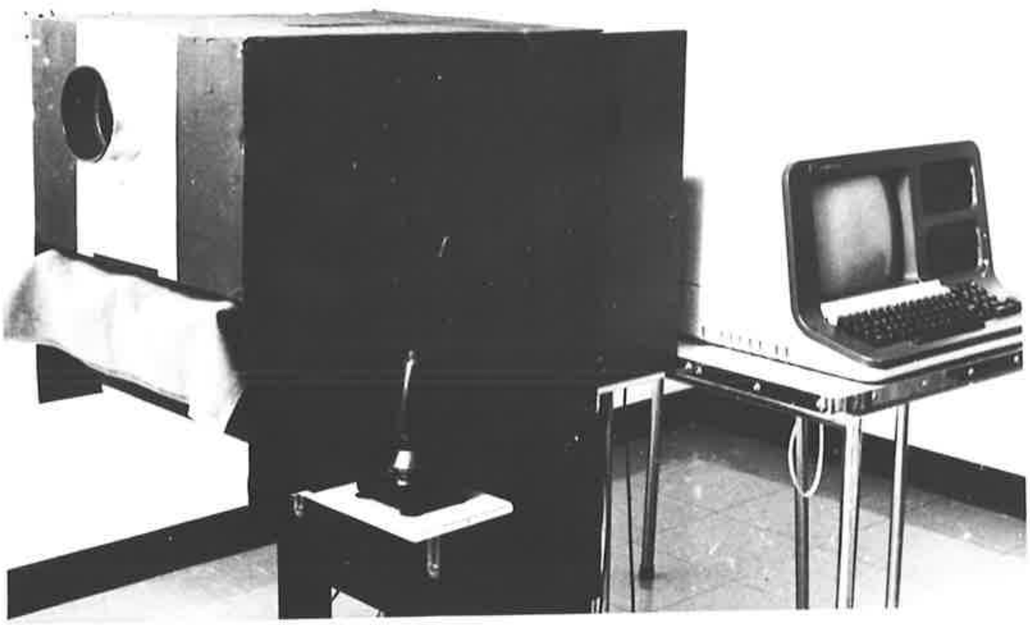


FIGURE 4.2: Handle on track - Used for presentation and reproduction of movement distances



<u>FIGURE 4.3:</u> Apparatus used in Experiment 1 - Vision precluded conditions

drawn on the monitor screen from left to right with a velocity of 30 mm/s. Holding the joy-stick to the left reduced the line length with the same velocity. Line lengths in the kinaesthetic modality were presented and reproduced by movement of the handle. When subjects completed reproduction of the standard stimulus they operated a micro-switch on the top of the joy-stick or handle, as appropriate, to register their response.

Procedure

Before testing, subjects were given practice in moving the handle, which they were instructed to move smoothly and with a velocity of about 30 mm/s. It was explained that the start of each trial would be signalled by a tone and that in the visual modality this would be followed immediately by a 3 second presentation of the standard stimulus line on the monitor screen. In the kinaesthetic modality the subjects were instructed to move the handle to the right, through the stimulus distance, until it was stopped by engagement of an electromagnetic clutch, and then to return it to the start point.

Presentation of the standard stimulus was followed by a 2 second interval, at the end of which a tone was presented. Subjects were instructed to respond to this signal by reproducing the standard stimulus length as accurately as possible, either by drawing a line on the monitor screen in the visual modality, or by "drawing" a line with the handle in the kinaesthetic modality. No time limit was imposed and subjects were allowed to adjust the line length until they were satisfied that it was the same as the standard stimulus. The only difference between conditions of vision was that in non-visual conditions the screening box was placed over the monitor to preclude the use of visual cues in the surround.

Six standard stimulus line lengths were used in all conditions: 25, 50, 75, 100, 125 and 150 mm. Line lengths were presented in random order, each length being presented 12 times, resulting in 72 trials. Prior to conducting experimental trials, subjects were given 12 practice trials in which two at each line length were included. Two conditions were tested in each of two sessions, with a rest of a few minutes between conditions. Half of the subjects were tested first in the visual followed by the non-visual conditions and half in the opposite order. Within conditions of vision half of the subjects were tested first in the VK and then the KV condition, and half in the opposite order.

Results

Error scores were analyzed using a 6 (Length) x 2 (Condition) x 2 (Vision) repeated measures analysis of variance with specific effects of length analyzed as planned comparisons of trend.

Absolute Error

Mean absolute error scores are shown in Figure 4.4 and Appendix 4.2. Analysis of these scores (see Appendix 4.3) revealed a significant effect of the linear trend for Length, $F(1, 55) = 203.63$, $p<.001$, and a significant interaction between Condition and the linear trend of Length, $F(1, 55) = 29.92$, $p<.001$. Figure 4.4 shows that absolute error increased with stimulus length in both conditions, but the increase was more marked in the VK than in the KV condition. Neither the difference between the mean error for the VK (27.5 mm) and KV (23.8 mm) conditions ($F(1, 11) = .70$, $p>.05$), nor between the vision available (26.9 mm) and vision precluded (24.5 mm) conditions ($F(1, 11) = 1.01$, $p.>05$) was significant.

Algebraic Error

An examination of the raw data revealed that in both the VKA and VKP conditions 80% of error scores were negative, and that in the KVA and KVP

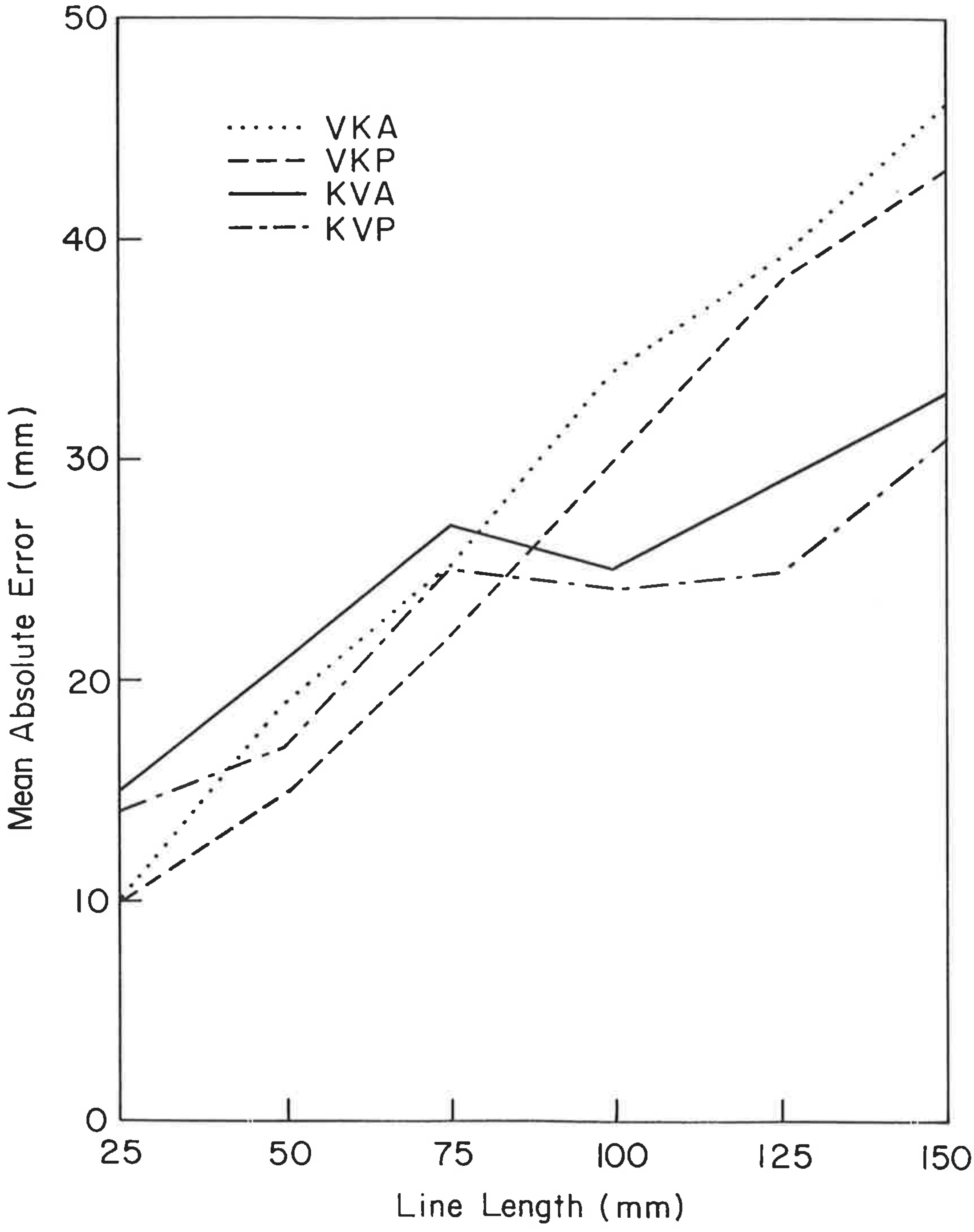


FIGURE 4.4: **Absolute Error - Experiment 1**

conditions 73% and 74%, respectively, were positive. That is, within both the VK and KV conditions the majority of scores were of the same sign, although negative in the former and positive in the latter. Since, then, Schutz and Roy (1973) have suggested that when the majority of error scores are of one sign absolute error is equivalent to algebraic error, within the VK and KV conditions absolute and algebraic error should be equivalent. To test this, mean algebraic error scores (shown in Figure 4.5 and Appendix 4.2) were analyzed (see Appendix 4.4).

There was a significant effect of the linear trend of Length, $F(1, 55) = 101.86$, $p<.001$, and a significant interaction between Condition and the linear trend of Length, $F(1, 55) = 225.18$, $p<.001$. Figure 4.5 shows that in the VK conditions negative algebraic error increased steadily with line length, whereas in the KV conditions positive algebraic error remained relatively constant over length. Mean error in the VK conditions (-22.7 mm) was significantly different from that in the KV (16.8 mm) conditions, $F(1, 11) = 27.52$, $p<.001$. There was no significant difference between mean error in the vision available (-3.3 mm) and vision precluded (-2.7 mm) conditions, $F(1, 11) = 0.07$, $p>.05$.

Residual Error

Residual error scores are shown in Figure 4.6 and Appendix 4.2. Analysis of these scores (see Appendix 4.5) revealed a significant effect for the linear trend of Length, $F(1, 55) = 143.32$, $p<.001$, and a significant interaction between Condition and the linear trend of Length, $F(1, 55) = 5.54$, $p<.05$. Figure 4.6 shows that residual error increased with length in both conditions, but the increase was more marked in the KV than in the VK condition. Mean error in the KV condition (13.7 mm) was significantly different from that in the VK condition (9.7 mm), $F(1, 11) = 8.37$, $p<.05$. There was no significant

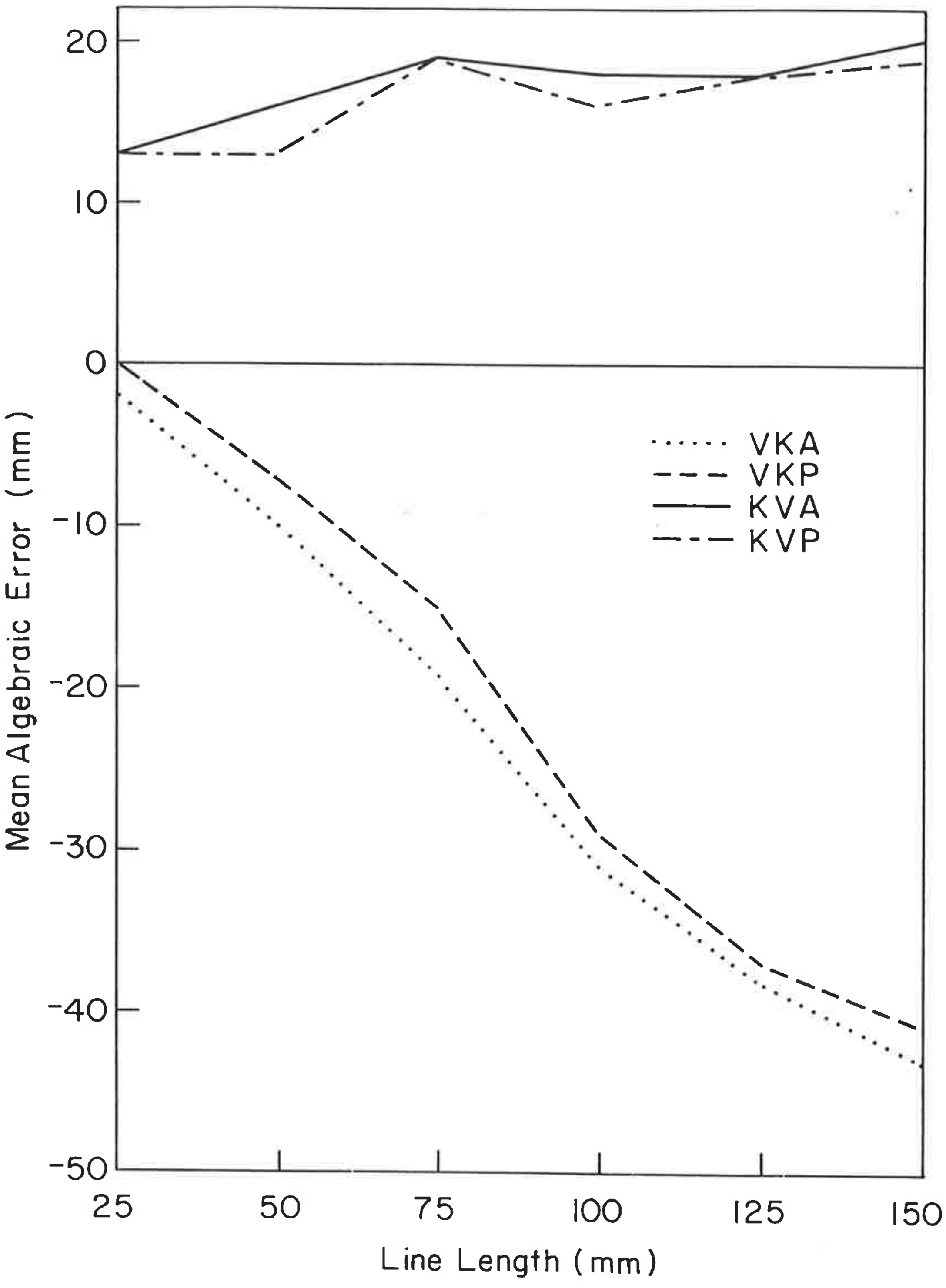


FIGURE 4.5: Algebraic Error - Experiment 1

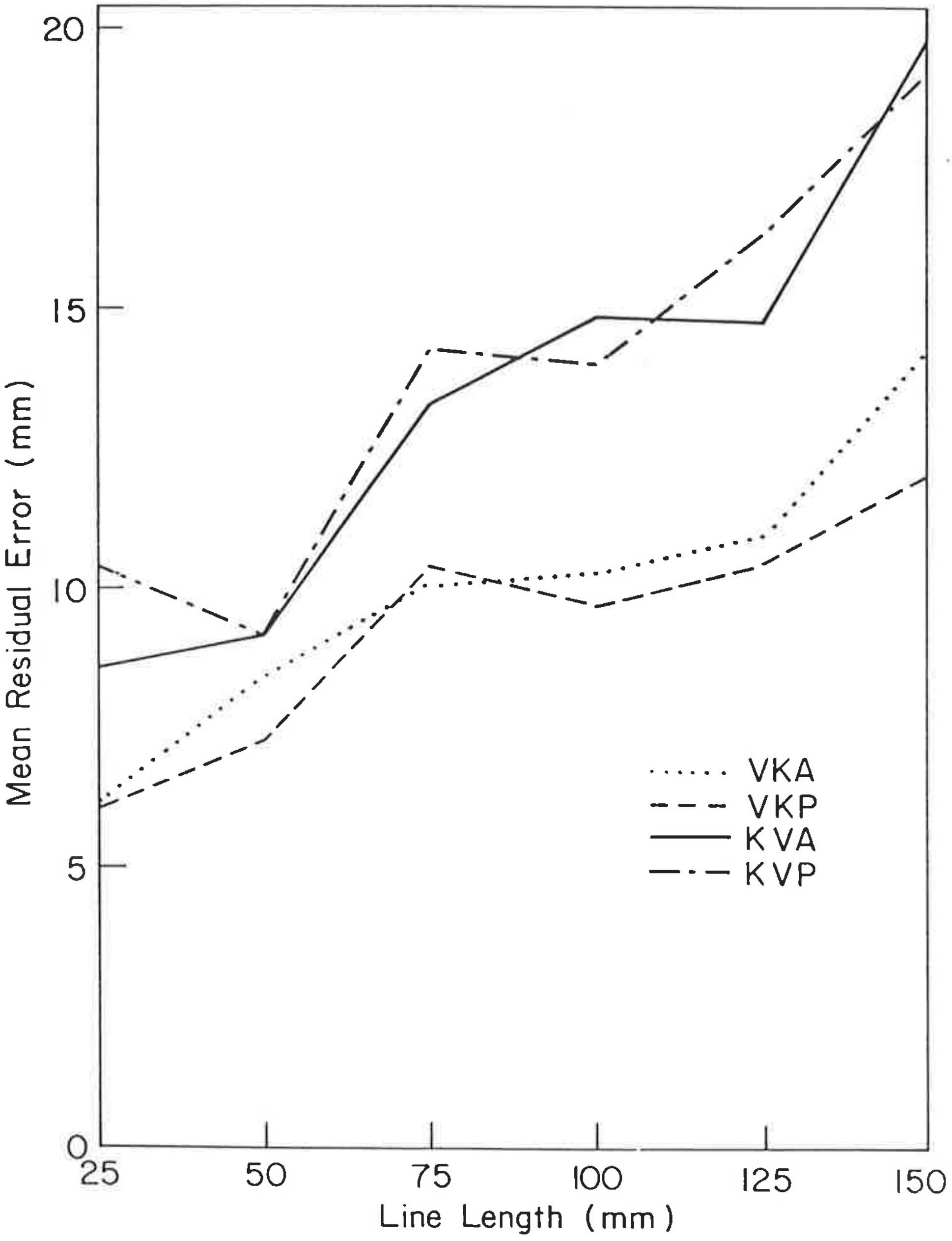


FIGURE 4.6: Residual Error - Experiment 1

difference between mean error in the vision available (11.8 mm) and vision precluded (11.7 mm) conditions, $F(1, 11) = 0.06, p>.05$.

Discussion

The hypotheses that the modality of presentation of the standard stimulus, and the availability of vision of the surround will influence the subject's choice of strategy, were not supported. In all conditions absolute error increased with the length of the standard stimulus, which is the pattern found by Hermelin and O'Connor (1975) and Salmoni and Sullivan (1976) in their distance conditions. Further, residual error increased with line length in all conditions, which is the pattern that would be expected when judgement of line length is involved. Thus, the pattern of both absolute and residual error scores suggest that subjects used a distance strategy in all conditions.

In this experiment the majority of error scores within both the VK and KV conditions were of one sign, being negative (i.e. underestimations) in the former and positive (i.e. overestimations) in the latter. Following Schutz and Roy (1973), because the majority of scores within conditions were of the same sign, it would be expected that absolute and algebraic error scores would be equivalent. However, the pattern of algebraic error scores differed distinctly from that for absolute error, negative error increasing with length in the VK conditions, but positive error remaining relatively constant in the KV conditions. Further, although there was no significant difference between the VK and KV conditions in absolute error, there was a significant difference in algebraic error.

The differential error pattern observed for algebraic error can be explained on the basis of perceptual bias. As was discussed in Chapter 3, judgements of length in the visual modality can be expected to be affected by contextual effects, resulting in overestimations or underestimations of length, such as are evident in the well known Müller-Lyer and Ponzo illusions. Consequently, it can be expected that, when the standard stimulus is presented in the visual modality, judgements of length will be affected by a perceptual bias associated with contextual factors, and that resulting errors in judgement will be related to the length of the stimulus line. By comparison, when the standard stimulus is presented in the kinaesthetic modality, no comparable bias would be expected. Consistent with this reasoning, algebraic error increased with length in the VK condition, but remained relatively constant in the KV condition.

Schutz and Roy (1973) have shown that absolute error is a function of algebraic error. Therefore, in the present experiment absolute error was a function of an algebraic error that differed between conditions. In particular, algebraic error revealed a bias that can be attributed to contextual factors which differed between conditions. Residual error, by comparison, provides a measure of performance after removing such bias. Although both absolute and residual errors increased with the length of the standard stimulus, whereas absolute error increased with length to a greater extent in the VK than in the KV condition, residual error increased more in the KV condition, i.e. the opposite pattern. Again, this difference can be attributed to the effect on absolute error of the perceptual bias revealed by the pattern of algebraic error. These findings show that, when absolute error is used as a measure of performance, contextual effects can be a confounding variable.

In addition to the effect of contextual factors, interviews with subjects following the experiment revealed that the outcome was affected by other confounding variables. Two subjects reported that, although the track used in the kinaesthetic modality was screened by a curtain, they could see part of their arms and that they had used this information as a cue. Another said that, on some trials, he had attempted to align the end of the visually presented standard stimulus line with the side of the viewing aperture. Several others remarked that they had thought that the standard stimuli had been grouped into short, medium and long lengths. These reports show that subjects are inclined to use any available information, or strategy, to assist them in their task.

EXPERIMENT 2

Although the hypotheses, that the modality of presentation of the standard stimulus and of availability of vision of the surround will influence the subject's choice of strategy, were not supported by the findings of Experiment 1, it is apparent that the outcome of that experiment was affected by several confounding variables. This experiment, therefore, was conducted to test the same hypotheses, after removing these confounding variables.

Method

Subjects

Twelve first year university students (five female and seven male) were used as subjects. All subjects were right hand dominant. These were not the same subjects who participated in Experiment 1.

Experimental Tasks and Apparatus

The experimental tasks and apparatus (apart from minor changes) were identical to those used in Experiment 1. Since interviews following Experiment 1 revealed that the viewing aperture could be used as a guide to reproduction, the screening box used to preclude vision of the surround was discarded. Also, since some subjects reported that they could see part of their arm and that they had used this information as a cue, the small curtain used to preclude vision of arm movements was replaced with an apron-like screen, attached to the apparatus and fastened around the subject's neck, which completely precluded vision of arm movements. In addition, to promote a greater sense of precision, the handle used in Experiment 1 was replaced with a small knob.

Procedure

The procedure followed was virtually identical to that used in Experiment 1. The only difference was the number and length of standard stimulus lines used. Thirty line lengths, ranging from 55 to 200 mm in increments of 5 mm, were used to preclude the possibility of a perception of grouping of lengths, as was reported by some subjects in Experiment 1. Line lengths were presented in random order, each length being presented twice, resulting in 60 trials. Prior to administering experimental trials, subjects were given five practice trials, using randomly selected lengths. In conditions when vision was available the room was dimly illuminated and, in those in which vision of the surround was precluded, testing was conducted in darkness.

Results

For purposes of analysis, the data were grouped into six categories of standard stimulus line lengths: 55-75, 80-100, 105-125, 130-150, 155-175 and 180-200 mm. Data were analyzed using a 6 (Length) x 2 (Condition) x 2 (Vision) repeated measures analysis of variance with specific effects of length analyzed as planned comparisons of trend.

Absolute and Algebraic Error

To confirm the finding in Experiment 1 of different error patterns, absolute and algebraic error scores were analyzed (see Appendices 4.6 and 4.7).

Mean absolute error was greater in the VK (35.1 mm) than the KV (22.1 mm) conditions, $F(1, 11) = 41.87, p<.01$. Also, there was a significant effect for the linear trend of Length, $F(1, 55) = 63.41, p<.01$, reproduction error increasing with length. There was a significant interaction between Condition and the linear trend of Length, $F(1, 55) = 43.23, p<.01$; absolute error increasing with the length of the standard stimulus in the VK conditions, but remaining relatively constant in the KV conditions.

Similarly, mean algebraic error was also greater in the VK (-33.8 mm) than in the KV (10.9 mm) conditions, $F(1, 11) = 35.90, p<.01$. Again, there was a significant effect for the linear trend of Length, $F(1, 55) = 80.28, p<.01$, reproduction error increasing with length. There was a significant interaction between Condition and both the linear ($F(1, 55) = 5.14, p<.05$) and quadratic ($F(1, 55) = 4.55$), $p<.05$) trends of length. In contrast with the pattern observed for absolute error, whilst in the VK condition algebraic error increased with the length of the standard stimulus, in the KV condition error decreased. However, the size of these effects was small.

Residual Error

Residual error scores are shown in Figure 4.7 and Appendix 4.8. Analysis of these data (see Appendix 4.9) revealed a significant effect for the linear trend of Length, $F(1, 55) = 28.60, p<.01$, and a significant interaction between Condition and the linear trend of Length, $F(1, 55) = 8.22, p<.01$. Figure 4.7 shows that, whilst in the VK condition there was a clear increase in residual error with length, in the KV condition error remained relatively

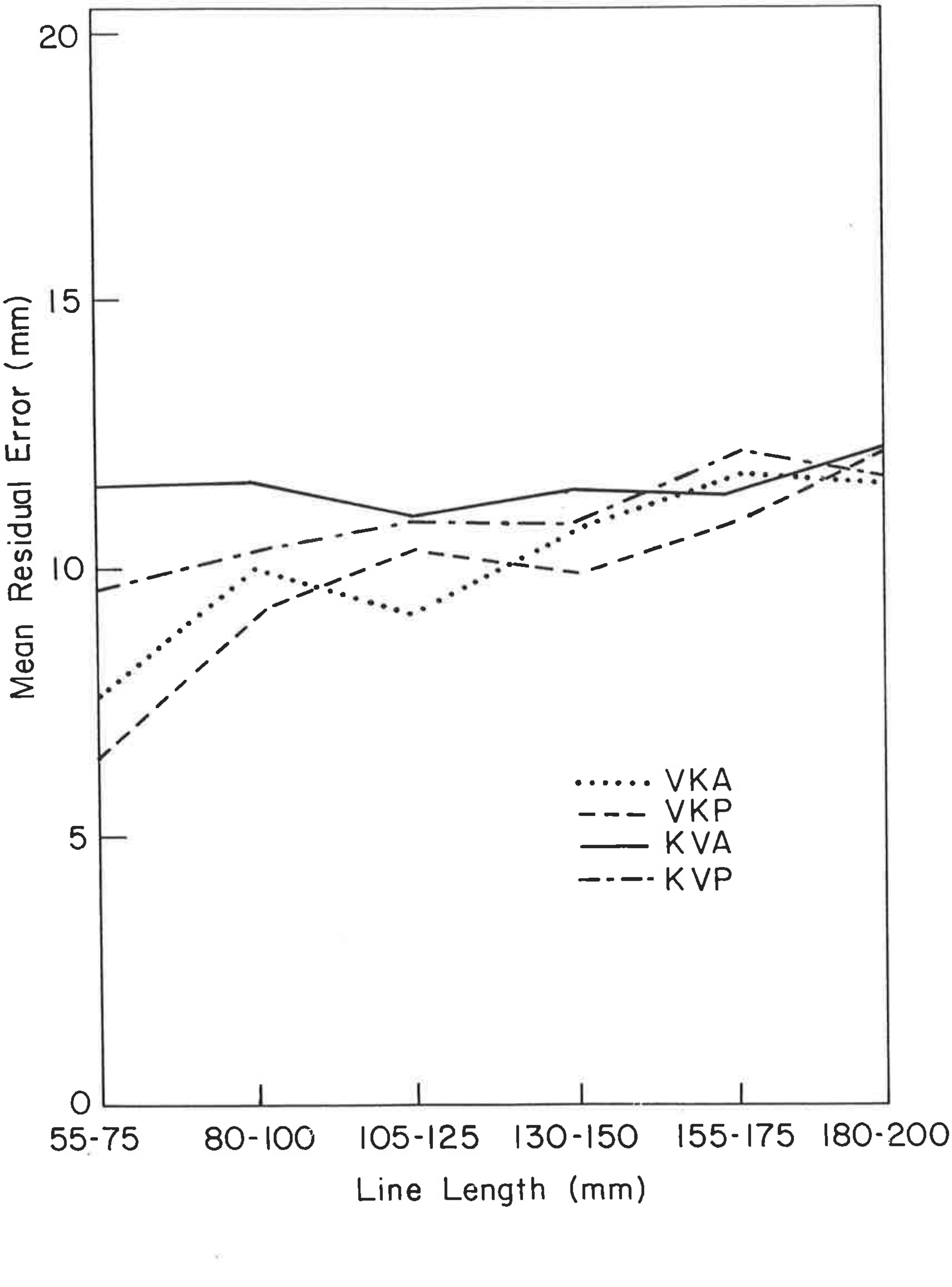


FIGURE 4.7: Residual Error - Experiment 2

constant. Neither the difference between the mean error for the VK (10.0 mm) and KV (11.3 mm) conditions ($F(1, 11) = 4.54, p>.05$), nor between the vision available (10.9 mm) and vision precluded (10.4 mm) conditions ($F(1, 11) = 0.97, p>.05$) was significant.

Discussion

The hypothesis that the modality of presentation of the standard stimulus will influence the subject's choice of strategy was supported. Residual error increased with the length of the standard stimulus in the VK condition, but remained relatively constant in the KV condition. It was pointed out in Chapter 3 that judgements of length are affected by variable error, i.e. overestimation or underestimation of length due to uncertainty, and that this error is related to the magnitude of the stimulus, whereas error in judgement of location is not related to the location of the stimulus. Therefore, since it provides a measure of variability, residual error would be expected to increase with the length of the standard stimulus when a distance strategy is used, but not when a location strategy is used. The present findings, therefore, suggest that *a distance strategy was used in the VK condition, but a location strategy was used in the KV condition.* However, the hypothesis that the availability of vision of the surround will influence the selection of strategy was not supported; no significant difference in residual error was found between vision available and vision precluded conditions.

Although in non-visual conditions subjects were tested in darkness, the monitor screen was clearly visible, and so could have provided a visual frame of reference. This is confirmed by one subject who reported judging the length of the standard stimulus in relation to the width of the monitor, and it is possible that others also may have done so. Failure to support the hypothesis that availability of vision of the surround will influence strategy selection may therefore be attributable to the availability of a visual frame of reference in the non-visual conditions.

A further possibility is that the outcome of this experiment was affected by an error of parallax. The track used for presentation and reproduction in the kinaesthetic modality was positioned in front of the monitor. Therefore, if in the VK condition the subject aligned the knob with the location of the end of the stimulus line, a negative error would result. Conversely, if in the KV condition the subject aligned the location of the end of the reproduction line with the position of the knob, a positive error would result. That is, a negative error bias would be expected in the VK condition, and a positive bias would be expected in the KV condition. This is the pattern of mean algebraic scores found. An error of parallax, however, would affect accuracy only when a location strategy is used, and the pattern of residual error suggests that a distance strategy was used in the VK conditions. Consequently, the negative bias in this condition cannot be attributed to such an error. An alternative explanation is that, since in the VK conditions the standard stimulus was presented as a line in the visual modality, judgement of length in these conditions was affected by contextual factors, resulting in a perceptual bias such as is demonstrated by the Müller-Lyer and Ponzo illusions, and that this resulted in underestimation of the length of the standard stimulus.

As in Experiment 1, there were distinct differences between the patterns of absolute and algebraic error scores. Moreover, it has been suggested that accuracy in the VK condition was affected by perceptual bias, whereas in the KV condition, since a location strategy was used, there would be no comparable effect. Therefore, since absolute error is a function of algebraic error (Schutz & Roy, 1973), absolute error was a function of algebraic errors that differed between conditions. Again, then, although in this experiment the patterns of absolute and residual error were similar, the findings suggest that absolute error is not an appropriate measure of performance.

EXPERIMENT 3

In addition to the effect of strategy on the relationship between error and the length of the standard stimulus, it was suggested in Chapter 3 that *suitability of modality to strategy can affect accuracy of reproduction.* It was argued that, although vision is suitable for judgements of distance, kinaesthesis is not. When a translation of information between modalities is required and a distance strategy is used, judgements of either the standard stimulus or reproduction length must be made in the kinaesthetic modality. Consequently, since kinaesthesis is not suitable for such judgements, a loss of accuracy would be expected to result. On the other hand, it was argued that both modalities are suitable for judgements of location. Consequently, when a translation of information between modalities is required and a location strategy is used, there will be no loss of accuracy attributable to unsuitability of modality to strategy. Suitability of modality to strategy, therefore, can be expected to affect performance when subjects are presented with a standard stimulus length in one modality which they are required to reproduce in the other. In particular, reproduction error can be expected to be greater when a distance, as compared with a location strategy, is used.

The findings of Experiment 2 show that, when instructed to reproduce the length of a visual standard stimulus line in the kinaesthetic modality (VK), subjects can use a distance strategy. However, the findings also suggest that, when instructed to reproduce the length of a standard stimulus movement distance in the kinaesthetic modality in the visual modality (KV) subjects are likely to adopt a location strategy. If, then, subjects comply with the experimenter's instructions and so use a distance strategy in the VK condition, but a location strategy in the KV condition, there will be a loss of accuracy in the VK condition because of the unsuitability of kinaesthesis for judgements of distance, but there will be no comparable loss in the KV condition. Consequently, reproduction error will be greater in the VK than in the KV condition. This can be described as the "loss hypothesis".

Contrary to this prediction, although the error pattern in Experiment 2 suggests that a distance strategy was used in the VK conditions and that a location strategy was used in the KV conditions, no significant difference in error was found between the VK and KV conditions. However, in this experiment the strategy used by subjects was not controlled. Subjects were instructed to reproduce the length of the standard stimulus and it was suggested that the availability of a visual frame of reference, in the form of the monitor screen, could have been used to facilitate the use of a distance strategy. Therefore, whilst the error pattern for the KV condition suggests that a location strategy was used, it is possible that not all subjects on all trials used this strategy. The use of a distance strategy in the KV conditions could, then, have resulted in greater error in the KV conditions also. This could account for the absence of a significant difference in error between conditions in Experiment 2.

Connolly and Jones (1970) found that error was greater in the KV than the VK condition, and their model explaining this asymmetry was described in Chapter 3 (see Figure 3.1). In brief, according to this model information is translated into the appropriate modality for reproduction, and information held in the kinaesthetic short-term store is subject to temporal decay, whilst that held in the visual short-term store is not. As a consequence, since in the VK condition information is held in the kinaesthetic short-term store during reproduction, whereas in the KV condition information is held in the visual short-term store, greater error results in the VK condition. However, as was discussed in Chapter 3, this model is open to question on the grounds of inconsistent findings.

In contrast with the Connolly and Jones (1970) explanation of asymmetry, which depends on the direction of information translation, i.e. VK or KV, the loss hypothesis attributes differences in error to the use of strategy, together with suitability of modality to strategy. Since it has been argued that loss of accuracy results from judgements of distance in the kinaesthetic modality, but there is no comparable loss for judgements of location, asymmetry should be found between strategies, rather than conditions. Therefore, if the loss hypothesis is valid, error in translation tasks should be greater when a distance, as compared with a location strategy, is used, regardless of the direction of translation.

Method

Subjects and Apparatus

The subjects and apparatus used in this experiment were the same as in Experiment 2.

Experimental Tasks

Subjects were presented with a standard stimulus in the visual modality which they were required to reproduce in the kinaesthetic modality (VK), or with a standard stimulus in the kinaesthetic modality which they were required to reproduce in the visual modality (KV). When performing these tasks, the subjects were instructed to use either a distance (D), or a location (L) strategy. This resulted in four experimental conditions: VKD, KVD, VKL and KVL.

When a distance strategy was required in the visual modality, the standard stimulus was presented on the monitor screen in the form of a line and was reproduced by drawing a line on the screen. In the kinaesthetic modality distance moved was presented and reproduced by movement of the knob on the track. When a location strategy was required in the visual modality the standard stimulus was represented by a small spot of light on the monitor screen and was reproduced by positioning the spot of light. Location in the kinaesthetic modality was presented and reproduced by movement of the knob on the track to a terminal location.

Thirty standard stimulus line lengths and movement distances used. As in Experiment 2, these ranged from 55 to 200 mm in increments of 5 mm. In location strategy 30 standard stimulus locations were also used. Each stimulus location was positioned to the right of the start-point used for stimulus lines or movement distances, at a distance equivalent to the length of a standard stimulus line or movement distance. To ensure that a distance strategy was used in distance conditions, the start-point of the line on the monitor screen was varied randomly by $\pm$ 25 mm with respect to the start-point of the knob on the track. In location conditions the start-points in both modalities were always aligned.

Procedure

For distance conditions subjects were instructed to reproduce the length of the standard stimulus by either drawing a line on the monitor screen using the joy-stick, or by "drawing" a line by movement of the knob on the track. It was explained that the start-points of lines in both the visual and kinaesthetic modalities would vary randomly and that, consequently, the location of the end-points of these lines was not a reliable cue. In location conditions subjects were instructed to reproduce the location of the spot of light on the monitor screen by positioning the knob on the track, or to reproduce the terminal location of the knob on the track by positioning the spot of light on the screen.

In location conditions the standard stimulus was positioned at the end of one of the line lengths. Each line length, or location was presented twice, resulting in a total of 60 trials. Before testing in each condition, the experimental task was explained and five practice trials were given, using randomly selected line lengths or locations. Experimental trials were administered immediately following practice trials. Two conditions were administered in each of two testing sessions, a rest of a few minutes being allowed between conditions. Half of the subjects were tested first in the distance followed by the location conditions and half were tested in the opposite order. Within strategies, half of the subjects were tested first in the KV and then the VK condition and half were tested in the opposite order.

Results

For purposes of analysis, error in the location conditions was measured in the same manner as in the distance conditions. That is, the location of the standard stimulus and of the subject's positioning of either the spot of light or the knob, as appropriate, were measured in relation to the zero point.

Residual Error

Residual error scores were converted into six line-length groupings: 55-75, 80-100, 105-125, 130-150,155-175, and 180-200 mm. The resulting error scores are shown in Figure 4.8 and Appendix 4.10. These data were analyzed

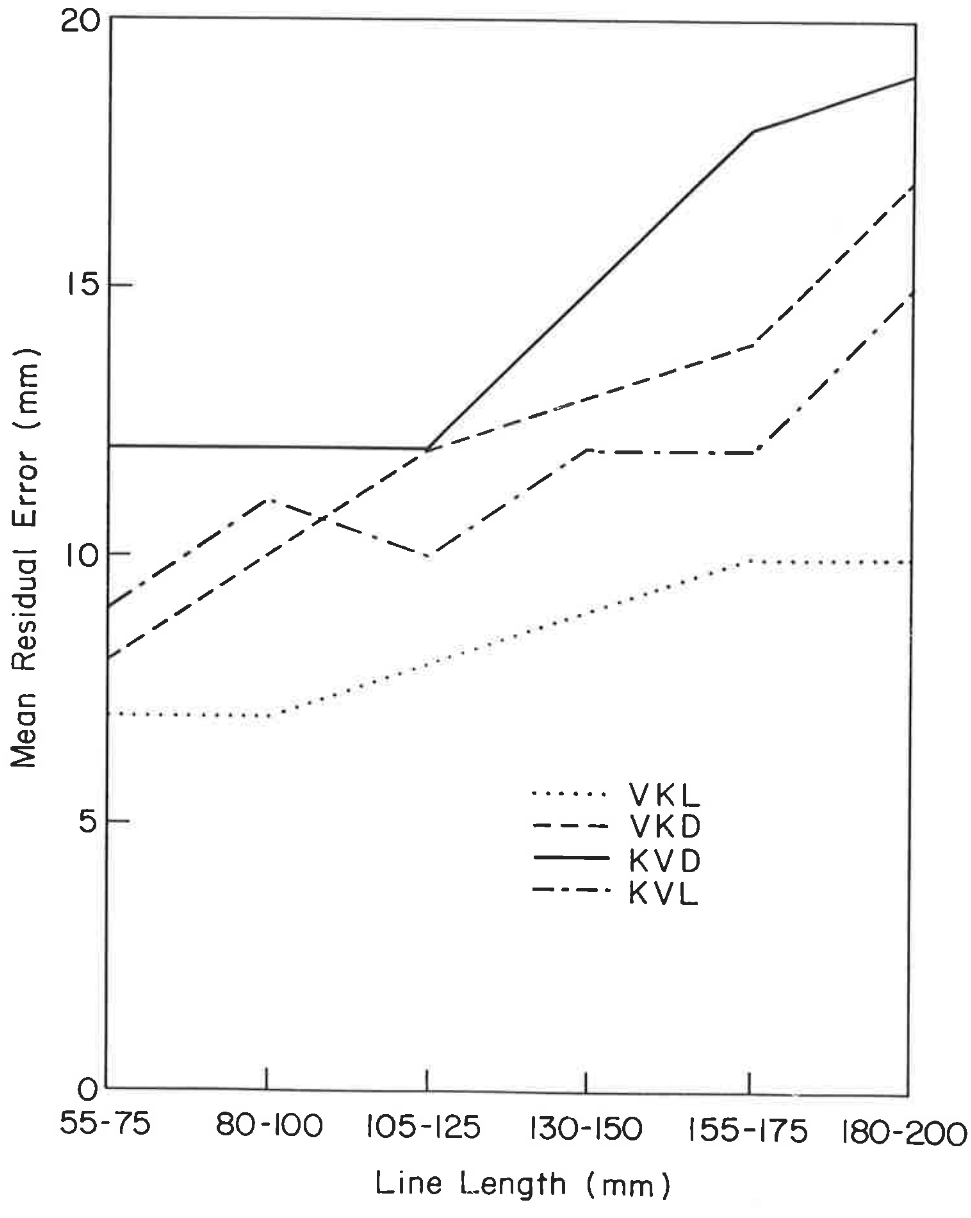


FIGURE 4.8: Residual Error - Experiment 3

using a three factor, 6(Length) x 2(Condition) x 2(Strategy) repeated measures analysis of variance with specific effects of length analyzed as planned comparisons of trend (see Appendix 4.11).

There was a significant main effect for the linear trend of Length, $F(1, 55) = 117.58$, $p<.01$, and a significant interaction between the linear trend of Length and Strategy, $F(1, 55) = 9.32$, $p<.01$. Figure 4.8 shows that residual error increased with length to a greater extent in the distance than the location strategy conditions.

Mean residual error was significantly greater in distance (13.6 mm) than in location (10.1 mm) conditions, $F(1, 11) = 69.13$, $p<.01$, and in KV (13.2 mm) than VK (10.5 mm) conditions, $F(1, 11) = 16.26$, $p<.01$. The Strategy x Condition interaction was not significant, $F(1, 11) = 0.18$, $p>.05$. Figure 4.8 shows that error was greater in both the VK and KV conditions when a distance strategy was used.

Regression Intercept

To investigate the possible effect of an error of parallax, the mean intercepts of the regressions of length reproduced on stimulus length were calculated. Table 4.1 shows that when a distance strategy was used the intercepts for both conditions were positive, whereas when a location strategy was used the intercepts were virtually identical in value, but opposite in sign.

Table 4.1

Mean Regression Intercepts (mm) - Experiment 3

		Condition	
		VK	**KV**
Strategy	**Distance**	3	29
	Location	-18	20

Discussion

The hypothesis that greater error will result when a distance as compared with a location strategy is used, regardless of the direction of translation of information, was supported; residual error was greater in both the VKD and KVD conditions. In both of these conditions judgements of movement distance in the kinaesthetic modality were required, whereas in the VKL and KVL conditions judgements of location only were required. Consequently, since it was argued in Chapter 3 that kinaesthesis is not suitable for accurate judgements of movement distance, but both modalities are suitable for judgements of location, a loss of accuracy would be expected to result in the VKD and KVD conditions, but no comparable loss would be expected in the VKL and KVL conditions. The finding of greater error in both distance strategy conditions, therefore, supports the loss hypothesis, according to which asymmetry between conditions can be attributed to differences in strategy, together with the suitability of modality to strategy.

An asymmetry between conditions was also found within strategies. For both distance and location strategies, error in the KV conditions was greater than in the VK conditions. It has been argued that, when a distance strategy is used, greater error in translation tasks can be attributed to the unsuitability of kinaesthesis for judgements of distance. Since judgements of distance in the kinaesthetic modality were required in both the VKD and KVD conditions, a comparable loss of accuracy would be expected in both. Consequently, no difference in accuracy would be expected between these conditions. On the other hand, it has been argued that both modalities are suitable for judgements of location. Consequently, no loss of accuracy would be expected in either the VKL or KVL conditions, and so no difference in accuracy would be expected between these conditions. The finding of greater residual error in the KV than the VK conditions, therefore, must be attributable to the modality in which the standard stimulus was presented.

It would be generally accepted that information is less precise in the kinaesthetic than the visual modality. Consequently, when the standard stimulus is presented in the kinaesthetic modality an error of judgement, attributable to the lack of precision of information in this modality, would be expected. Because of the comparative lack of precision, then, error should be greater when the standard stimulus is presented in the kinaesthetic modality, regardless of reproduction modality. Moreover, this would be so for both distance and location strategies. Thus, the finding of greater error, in both the KVD and KVL than the VKD and VKL conditions, can be attributed to a lack of precision in the information provided by the standard stimulus.

Two sources of error, therefore, can be expected to affect the accuracy of reproduction of a standard stimulus when a translation of information between modalities is required. When judgements of movement distance are required, accuracy will be detrimentally affected by the unsuitability of kinaesthesis for such judgements. *In addition*, when the standard stimulus is presented in the kinaesthetic modality, because of the lack of precision in this modality as compared with vision, a loss of accuracy will result. In particular, although Salmoni and Sullivan (1976) suggest that both modalities are equally suitable for judgements of location, when a standard stimulus location is presented in the kinaesthetic modality, a loss of accuracy can be expected.

Analysis of the regression data revealed that when a distance strategy was used the intercepts for both conditions were positive, whereas when a location strategy was used the two intercepts were virtually identical in value, but positive in the KV condition and negative in the VK condition. When a distance strategy is used, since no alignment is involved, an error of parallax would have no effect, and so no differential error bias would be expected between the VKD and KVD conditions. By comparison, when a location strategy is used, alignment of the standard stimulus and reproduction locations would result in the pattern of error bias observed between the VKL and KVL conditions. The present results, therefore, suggest that the outcome of this experiment was affected by an error of parallax in the location conditions. This supports the suggestion that the outcome of Experiment 2 may similarly have been affected by an error of parallax.

Residual error increased with the distance of the stimulus location from the zero point when a location strategy was employed, although not to the same extent that it increased with length in the distance conditions. In part, this can be attributed to variations in strategy used by subjects. Thus, some subjects subsequently reported using distance as well as location information in the location conditions. The standard stimulus location could have been judged in relation to a fixed reference, and the side of the monitor screen provided such a reference. Using this technique would require judgement of the distance from the reference point to the location, i.e. a distance strategy. Consequently, error would be related to the distance of the stimulus location from the side of the monitor screen, and so in turn to the distance of the stimulus from the start point of the line length or movement distance at the end of which it was positioned. Therefore, it is probable that the results for residual error in the location conditions were affected by the use of this strategy by some subjects.

General Discussion

The results of Experiment 2 show that, although subjects are instructed to reproduce length, the modality in which the standard stimulus is presented can influence their choice of strategy. When the standard stimulus is presented in the visual modality subjects can comply with instructions to use a distance strategy, whereas when the standard stimulus is presented in the kinaesthetic modality they are likely to use a location strategy, and these strategies are associated with different error patterns. Moreover, the results of Experiment 3 show that, when a translation between modalities is involved, variation in strategy can result in error difference between conditions, error being greater when a distance, as compared with a location strategy, is used. Also, the results of Experiment 3 suggest that the modality in which the standard stimulus is presented can affect reproduction accuracy. Because of lack of precision in the kinaesthetic, as compared with the visual modality, reproduction error will be greater when the standard stimulus is presented in the kinaesthetic modality. Both strategy and the modality in which the standard stimulus is presented, therefore, can be confounding variables in experiments of this design.

In addition, the subject's performance can be affected by the use of visual cues in the surround. Clearly, the use of such cues can be expected to facilitate reproduction when a location strategy is used, but as revealed in an interview with a subject following Experiment 2, a visual frame of reference (in this case the monitor screen) can also be used to assist in judgement of the length of the standard stimulus. Such visual cues can be excluded by testing subjects in complete darkness. For example, Marteniuk and Rodney (1979) presented the standard stimulus using a line of luminescent green paint in a dark room. When the subjects are children, however, testing in complete darkness for any length of time can be expected to result in some anxiety. Apart from the effect on the subject's performance, this would be ethically unacceptable.

It seems unlikely that Millar's (1972) approach, of presenting standard stimuli in a box with a viewing aperture, will preclude visual cues in the surround. The side of the viewing aperture can be used as a cue to facilitate the use of a location strategy and the viewing aperture can be used as a visual frame of reference to facilitate the use of a distance strategy. An alternative approach is to preclude the use of visual cues by the use of a screen. Newell et al. (1979), for example, used an homogeneous black background for this purpose. However, whilst such a screen can preclude the use of location cues, there must be some opening in which the standard stimulus is presented, and again this can be used as a visual frame of reference. A further potential problem, suggested by the results of Experiments 2 and 3, is that the positioning of items of equipment can result in a parallax error if a location strategy is used.

Finally, when a distance strategy is used, contextual effects can be expected to result in a perceptual bias, and the findings of Experiments 1 and 2 suggest that performance in the VK and KV conditions was differently affected by such a bias. Contextual factors can be expected to vary between experimental conditions and to be difficult, if not impossible, to determine. Moreover, perceptual bias is reflected in algebraic error. Because of this, and the finding in Experiments 1 and 2 that the pattern of algebraic error, of which absolute error is a function, differed between conditions, it is evident that absolute and algebraic error are not appropriate measures of performance.

Several confounding variables, then, can affect the outcome of experiments following the Connolly and Jones (1970) design, and it is likely that previous findings have been affected by them. In particular, differences in strategy could account for the inconsistent findings of asymmetry between translation conditions discussed in Chapter 3. Also, it is likely that a visual frame of reference (e.g. the viewing aperture) could have affected the results of studies of this type. Further, it is possible that in some experiments an unrecognized error of parallax might have resulted in error biases. The most pervasive factor affecting reproduction accuracy, however, is likely to be the influence of contextual factors on judgements and their effect on algebraic, and hence absolute error.

In summary, it is difficult to design an experiment of this type in which all possible confounding variables are completely excluded. However, subjects can be forced to use a distance strategy by the use of a randomly varying offset between the start points of the standard stimulus and reproduction lines. Also, it can be expected that, if they are instructed to use a location strategy, and if only location information is available, subjects will comply with the experimenter's instructions. The use of visual cues in the surround to facilitate the use of a location strategy can be precluded by the use of a screen. Whilst there must be an opening in such a screen to allow for presentation of the standard stimulus, and for reproduction in the visual modality, the use of this as a visual frame of reference can be minimized, if not prevented, by obscuring the extremities of this opening. Although there will always be contextual effects that will result in perceptual bias, the effect of this bias can be excluded by the use of residual error as a measure of performance.

CHAPTER 5

PERCEPTION, TRANSLATION AND MOTOR ABILITY

The results of Experiments 1 to 3 show that both strategy and modality of presentation can affect accuracy of reproduction of a standard stimulus by adults. Connolly and Jones (1970) and Hulme et al. (1983) found that, in children, reproduction accuracy improved with age. Moreover, in Experiments 1 to 3 the experimental tasks required the translation of information between modalities; reproduction of a standard stimulus within-modality was not investigated. The effect of strategy and modality of presentation on the performance of children, both within and between modalities, therefore needs to be investigated.

EXPERIMENT 4

Motor Ability and Perceptual Judgement

It was argued in Chapter 4 that information is less precise in the kinaesthetic than in the visual modality. Because of this, for both distance and location strategies, reproduction error should be greater in the kinaesthetic than in the visual modality. Further, it was argued in Chapters 3 and 4 that kinaesthesis is not suitable for judgements of movement distance, but is suitable for judgements of location. Therefore, reproduction error should be greater in the kinaesthetic modality when a distance, as compared with a location strategy, is used. Although vision is suitable for judgements of both distance and location, it was argued in Chapter 4 that judgements of distance are more difficult than are judgements of location, and so within the visual modality error should also be greater when a distance, as compared with a location strategy, is used. For both modalities, therefore, error should be greater when a distance strategy is used.

In both the Connolly and Jones (1970) and the Hulme et al. (1983) experiments, performance was found to improve with age. This can be attributed to the development of perceptual ability during childhood discussed in Chapter 2. However, since it has been argued that kinaesthesis is not suitable for accurate judgements of movement distance, this would be expected to be so at all ages, and so there should be little or no improvement with age in ability to judge movement distance in the kinaesthetic modality. By comparison, since kinaesthesis is suitable for judgements of location, and vision is suitable for judgements of both location and distance, it would be expected that ability to judge location in the kinaesthetic modality, and both distance and location in the visual modality, should improve with age.

In addition, as was discussed in Chapter 2, both vision and kinaesthesis are important in the performance of motor skills. Therefore, it is expected that improved perceptual ability should be accompanied by improvement in motor ability. If, however, as was argued in Chapter 3, kinaesthesis is not suitable for accurate judgements of distance, ability to judge distance in the kinaesthetic modality should contribute little to motor ability. That is, there should be a low correlation between motor ability and accuracy in judgement of movement distance in the kinaesthetic modality. By comparison, it was also argued that kinaesthesis is suitable for judgements of location, and that vision is suitable for judgements of both distance and location. Therefore, the ability to judge location in the kinaesthetic modality, and both location and distance in the visual modality, should contribute to motor ability. That is, there should be a strong correlation between motor ability and accuracy in judgements of location in the kinaesthetic modality, and of both location and distance in the visual modality.

In summary, this experiment was designed to test the hypotheses that, in within-modal reproduction tasks:

1. For both distance and location strategies, error will be greater in the kinaesthetic than the visual modality.
2. For both modalities, error will be greater when a distance, as compared with a location strategy, is used.
3. There will be an improvement with age in accuracy of judgement of location in the kinaesthetic modality, and of both distance and location in the visual modality, but little or no improvement in judgement of distance in the kinaesthetic modality.
4. There will be a strong correlation between motor ability and accuracy of judgement of location in the kinaesthetic modality, and of both distance and location in the visual modality, but a low correlation with accuracy of judgement of distance in the kinaesthetic modality.

Method

Subjects

The subjects in this experiment were 36 normal children, including 12 (6 boys and 6 girls) in each of three groups. The mean ages of the children in these groups were: 8 years 7 months (range 7-9 to 8-11), 10 years 6 months (range 10-3 to 10-10), and 12 years 4 months (range 11-8 to 12-7). It is generally accepted that motor ability develops during childhood and this age range was chosen to provide variation in motor ability. The children were selected by class teachers on the basis of being at least average in both motor and academic ability. Five of the children were left-hand dominant and 31 were right-hand dominant.

Experimental Tasks and Apparatus

Subjects were presented with standard stimulus line lengths and locations which they were required to reproduce as accurately as possible. Line lengths and locations were presented and reproduced within either the visual (V) or kinaesthetic (K) modalities, and subjects were instructed to reproduce either length, i.e. "distance" (D), or location (L). This resulted in four experimental conditions: VVD, KKD, VVL and KKL.

The apparatus used in this experiment was the same as that used in Experiment 3, but with two modifications. To preclude the use of visual cues in the surround, and of the monitor screen as a visual frame of reference, a hardboard screen covered with homogeneous black plastic was placed in front of the monitor. This screen, shown in Figure 5.1, was 0.65 m in height and 1.4 m in width, so that it extended into the subject's area of peripheral vision. A 25 mm slot, in which a piece of clear plastic was placed, extended horizontally throughout the width of the screen. The plastic was painted matt black where the screen extended beyond the monitor and the paint was faded at its sides. This resulted in a viewing aperture, about 30 cm wide, with no clearly defined boundaries. The plastic was covered with black voile material to prevent reflections. To preclude the possibility of parallax error, the monitor was positioned directly above the track.

The apparatus was positioned so that "zero points", at the left of the monitor screen and at the left end of the track, were aligned. In distance strategy conditions the left extremity of the standard stimulus line, and the start point for the standard stimulus movement distance, were randomly

FIGURE 5.1: Screen used in Experiment 4

located at a position 25, 50, 75 or 100 mm to the right of the zero point, but the start point for reproduction, in both modalities, was located at the zero point. This resulted in a randomly varying "offset" between the start points for presentation and reproduction. When a location strategy was required, the standard stimulus in the visual modality was presented as a spot of light on the monitor screen. In the kinaesthetic modality the standard stimulus was presented by movement of the knob to a terminal location. Therefore, to preclude the use of movement distance as a cue, the same procedure was followed as in the distance strategy conditions. For left-hand-dominant subjects, the zero points were located on the right of the apparatus, and subjects moved the knob with their left hand so that all movements were extensor.

Procedure

The procedure followed in this experiment was near-identical to that used in Experiment 3. The difference was that the standard stimulus was presented and reproduced in the same modality. Also, because the subjects were children it was thought that lapses in attention might affect their performance. Therefore, the standard stimulus was presented for 5 seconds, and the number of standard stimuli was reduced to 25, each being presented once. Standard stimulus lengths in the distance strategy conditions ranged from 80 to 200 mm, in increments of 5 mm. In location strategy conditions the standard stimulus was located at the end of one of these line lengths.

Before testing in experimental conditions, the subject's handedness was determined using the six primary questions from Annett's (1970) test, and motor ability was assessed using the Gubbay (1989) test.[1] The

1. The Gubbay (1989) test was discussed in Chapter 2. Although this test can be criticized, it has been used by a number of investigators and it was used here for consistency with the Hulme et al. (1982a, 1982b, 1983, 1984) studies.

experimental tasks were administered in four separate sessions, each of about 20 minutes duration. Half of the subjects were tested first in the distance and then in the location conditions and half were tested in the reverse order. Within these groups, half of the subjects were tested first in the visual followed by the kinaesthetic modality, and half were tested in the opposite order. To maintain the children's interest, the experimental conditions were portrayed as aeroplane flying games. Children who had a defect of visual acuity wore their prescribed spectacles during the experiment.

In distance conditions it was explained that the start point of the line drawn on the screen, or of the movement distance, would always differ from that of the stimulus line or movement distance and that, consequently, the location of the end-point of the standard stimulus was not a reliable cue. In the KKL condition it was explained that the start point would always be different and that, consequently, the movement distance of the knob was not a reliable cue.

Results

Motor Ability Scores

Using a procedure similar to that adopted by Hulme et al. (1982a, 1983) and Murphy and Gliner (1988), scores for the five items in the Gubbay test were transformed to z scores and summed to give a composite score. A high score on the *Throw, clap hands then catch tennis ball* item (i.e. number of claps) reflected good performance. By comparison, scores on the remaining items (*Roll ball with foot, Thread 10 beads, Pierce 20 pinholes, and Posting box*), i.e. time to complete the task, reflected poor performance. Therefore, the sign of the *z* scores for the clap and catch item was reversed before summation and, to remove negative signs, the summed *z* scores were subtracted from 10. This procedure can be questioned on the basis that the test items are likely not to have equal discriminating value, but it is the only alternative when using relatively small sample sizes.

The resulting composite motor scores are shown in Appendix 5.1, and the mean scores are shown in Table 5.1. These scores were analyzed using a 2(Sex) x 3(Age) analysis of variance (see Appendix 5.2). This analysis revealed a significant main effect for Age, $F(2, 30) = 24.31$, $p<.001$, and Table 5.1 shows that motor ability improved with increase in age. Also, there was a significant main effect for sex, $F(1, 30) = 5.81$, $p<.05$), Table 5.1 showing that the mean score for females was lower than that for males. The Sex x Age interaction was not significant, $F(2, 30) = 2.35$, $p>.05$.

Table 5.1

Mean Composite Motor Ability Scores in Experiment 4

Age	Sex			
	Male		Female	
	Mean	SD	Mean	SD
8	8.5	(2.8)	5.3	(2.1)
10	9.8	(1.3)	10.3	(2.3)
12	14.3	(0.8)	11.8	(2.9)
Mean	10.9	(3.1)	9.1	(3.6)

Residual Error

Residual error scores are shown in Appendix 5.3. For purposes of analysis, the data were grouped into five categories of standard stimulus line length: 80-100, 105-125, 130-150, 155-175 and 180 - 200 mm.

To investigate the possibility of a differential effect of sex, these data were analyzed using a 2(Sex) x 3(Age) x 2(Modality) x 2(Strategy) analysis of variance with repeated measures on the last two factors (see Appendix 5.4). This analysis revealed no significant difference between the mean residual error scores for boys (15 mm) and girls (14 mm), $F(1, 30) = 1.62$, $p>.05$, and no two or three-way interactions involving Sex was significant. The small four-way interaction was significant, $F(2, 30) = 4.04$, $p<.05$, but the meaning of this interaction was not clear. Sex, therefore, was disregarded and the data were collapsed over this factor.

The resulting residual error scores were analyzed using a mixed design, 3(Age) x 2(Modality) x 2(Strategy) x 5(Length) analysis of variance with specific effects of length analyzed as planned comparisons of trend (see Appendix 5.5). This analysis revealed that the main effects of Age ($F(2, 33) = 7.85$, $p<.005$) and both the linear ($F(1, 132) = 29.22$, $p<.001$) and quadratic ($F(1, 132) = 5.35$, $p<.05$) trends of length were significant. The main effect of Strategy was not significant, $F(1, 33) = 2.04$, $p>.05$, but there was a significant Strategy x Length interaction for the linear trend of length, $F(1, 132) = 9.29$, $p<.005$. Also, there was a significant Age x Length interaction for the linear trend of length, $F(2, 132) = 3.68$, $p<.05$, and a significant Age x Strategy x Length interaction for the linear trend of length, $F(2, 132) = 6.58$, $p<.005$. Mean error scores, collapsed over modality, are shown in Figure 5.2, which shows that accuracy improved with increase in age, mean error decreasing from 16.4 to 14.8 to 12.1 mm,

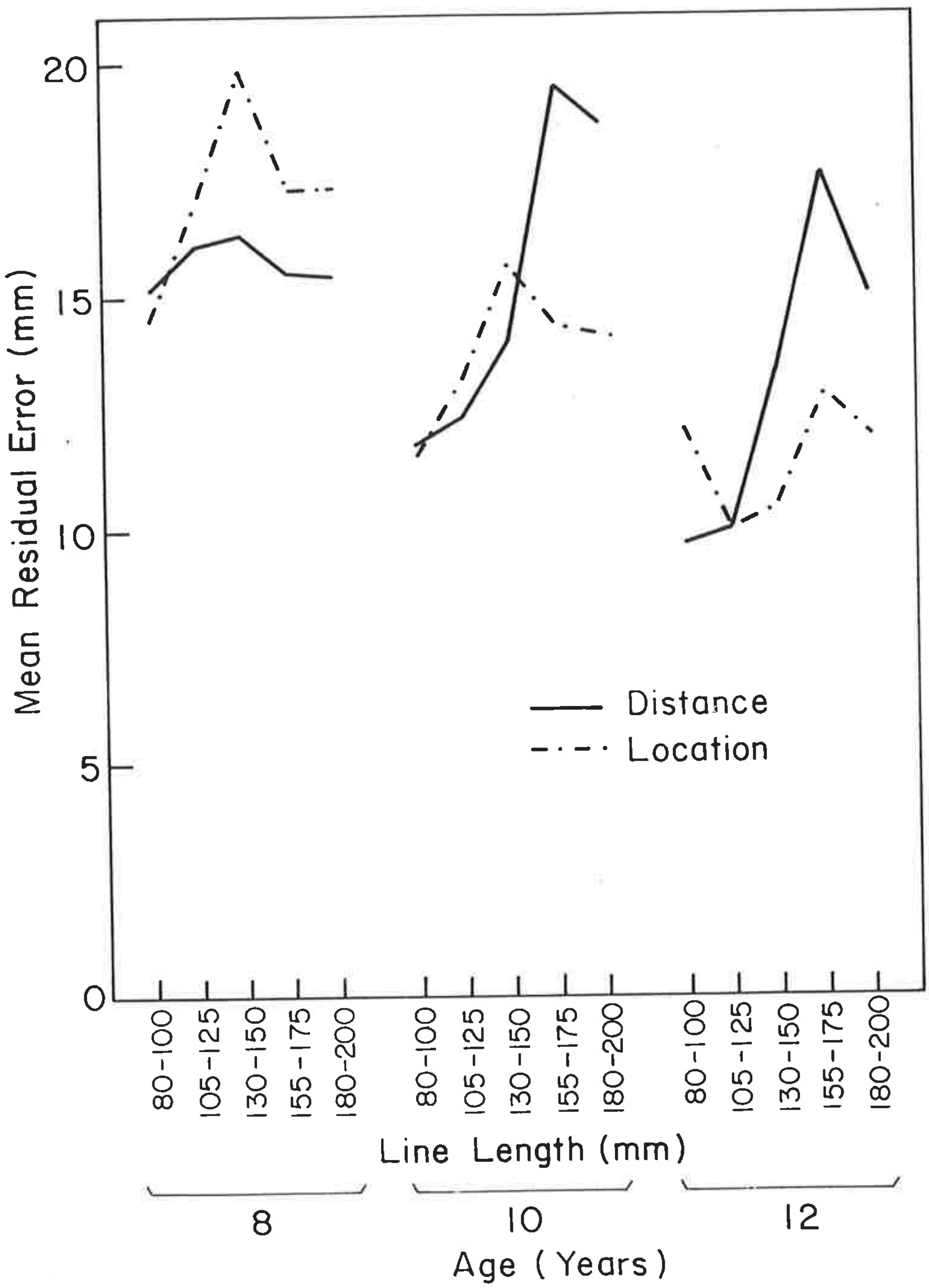


FIGURE 5.2: Residual Error (collapsed over modality) for 8, 10 and 12-year-old children in Experiment 4

but that the pattern of error differed with age. Figure 5.2 shows that for the 8-year-old group error increased with length in location, but not distance strategy conditions, whereas for the 10 and 12-year-old groups error increased with length to a greater extent in distance than location strategy conditions.

Because the pattern of residual error indicated that the 8-year-old children had not used distance and location strategies as instructed, the scores for these children were deleted and the data for the 10 and 12-year-old children were analyzed (see Appendix 5.6). This analysis revealed a significant effect for the linear trend of Length, $F(1, 88) = 37.03$, $p<.001$) and a significant Length x Strategy interaction for the linear trend of length, $F(1, 88) = 20.75$, $p<.001$, but the Length x Strategy x Age interaction was not significant, $F(4, 88) = 0.67$, $p>.05$. Mean residual error scores, collapsed over Age and Modality, are shown in Figure 5.3, which shows that error increased with the length of the standard stimulus in distance strategy conditions, but remained relatively constant in location strategy conditions.

Mean residual error was greater in the kinaesthetic (17.6 mm) than in the visual modality (9.3 mm), $F(1, 22) = 164.68$, $p<.001$. Also, mean error was significantly greater in distance (14.4 mm) than in location (12.5 mm) strategy conditions, $F(1, 22) = 7.61$, $p<.05$. The Strategy x Modality interaction was not significant, $F(1, 22) = 0.26$, $p>.05$, but there was a significant Modality x Length interaction for the linear trend of length, $F(1, 88) = 4.75$, $p<.05$. An examination of the data revealed that error tended to increase with length to a greater extent in the visual than the kinaesthetic modality, but the difference was small.

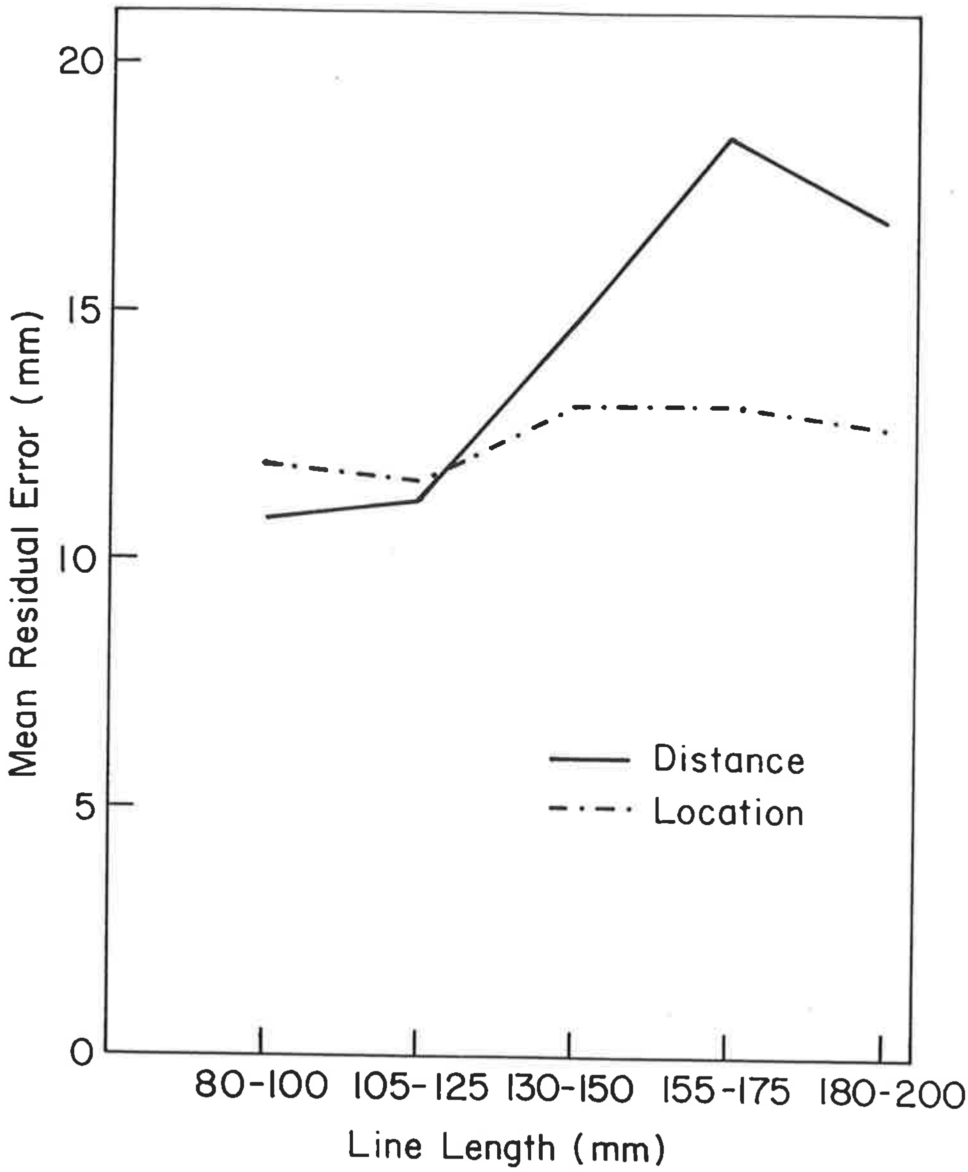


FIGURE 5.3: Residual Error (collapsed over age and modality) for 10 and 12-year-old children in Experiment 4

The analysis also revealed that mean residual error for the 10-year-old group (14.8 mm) was significantly greater than that for the 12-year-old group (12.1 mm), $F(1, 22) = 6.21$, $p<.05$, and there was a significant Age x Strategy x Modality interaction, $F(1, 22) = 6.20$, $p<.05$. Mean residual error scores, collapsed over length, are shown in Figure 5.4. This Figure shows that there was a similar improvement in accuracy with age in the kinaesthetic modality for both distance and location strategies, and in the visual modality for the location strategy. By comparison, there was no improvement with age in the visual modality for accuracy in judgements of distance.

Correlations

Pearson product moment correlations were calculated between motor ability and residual error scores for each condition. Higher motor ability scores were associated with lower error scores, resulting in negative correlations.

Although the pattern of residual error showed that the 8-year-old children had not used distance and location strategies as instructed, the scores for the children in this group were included in the initial analysis so as to use the maximum available range of abilities. The resulting correlations are shown in Table 5.2. This Table shows that, in the KKD condition the correlation was low and not significant, whereas for all other conditions correlations were moderately strong and significant. Comparisons between correlations were made using the procedure suggested by Ferguson (1966). This revealed that the difference between correlations for the VVD and KKD conditions was significant, $t(33) = 2.29$, $p<.05$, but that the difference between correlations for the VVL and KKL conditions was not significant, $t(33) = .67$, $p>.05$.

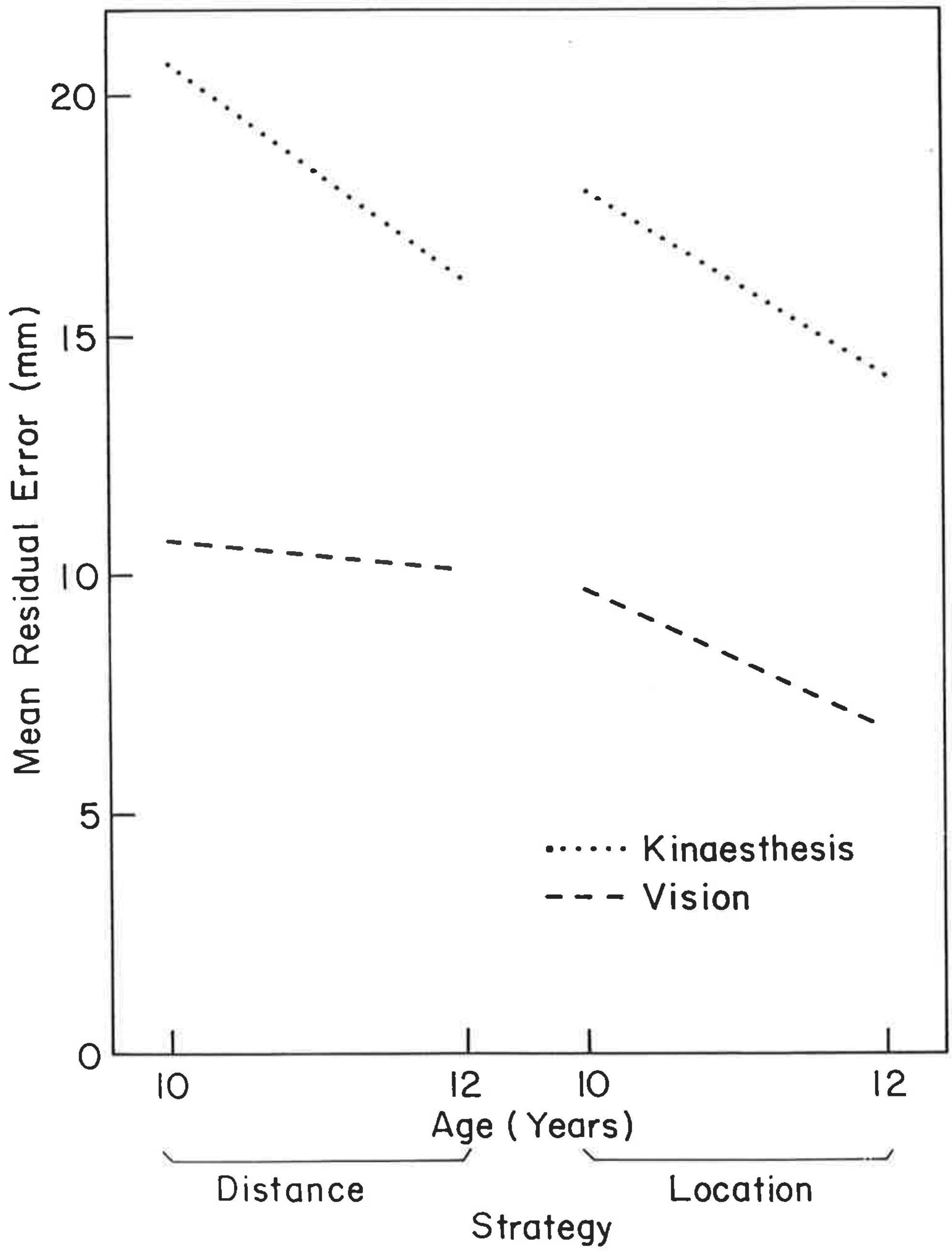


FIGURE 5.4: Residual Error (collapsed over length) in Experiment 4

Table 5.2

Correlations Between Motor and Residual Error Scores in Experiment 4 for 8, 10 and 12-year-old Children

	r	*p*
VVD	-.59	<.001
KKD	-.24	>.05
VVL	-.59	<.001
KKL	-.67	<.001

Scores for the 8-year-old children were then deleted from the data and correlations were calculated between motor ability and residual error scores for the 10 and 12-year-old children. The resulting correlations are shown in Table 5.3. This Table shows that, for the 10 and 12-year-old children, correlations in all conditions were moderately strong and significant. However, comparisons revealed that correlations in the VVD and KKD conditions ($t(21) = 0.13, p>.05$), and the VVL and KKL conditions ($t(21) = 0.71, p>.05$) were not significantly different.

Table 5.3

Correlations Between Motor and Residual Error Scores in Experiment 4 for 10 and 12-year-old Children

	r	*p*
VVD	-.47	<.05
KKD	-.45	<.05
VVL	-.40	<.05
KKL	-.54	<.005

Discussion

The finding that, for the 10 and 12-year-old groups, residual error scores increased with line length to a greater extent in distance, as compared with location strategy conditions, is similar to the earlier findings of Hermelin and O'Connor (1975) and Salmoni and Sullivan (1976) in their distance and location conditions. More particularly, the pattern of residual error is similar to that found in Experiment 3 for distance and locations strategies respectively, suggesting that the 10 and 12-year-old children used distance and location strategies as instructed. In contrast, the finding of an opposite error pattern for the 8-year-old group suggests that these children did not use distance and location strategies as instructed. When testing the 8-year-old children in the kinaesthetic modality, it became obvious that they had difficulty understanding the difference between reproducing movement distance, as distinct from location. The unexpected error pattern observed for the 8-year-old group, therefore, can be attributed to difficulty experienced by these children in understanding task requirements.

When the data for the 10 and 12-year-old groups were analyzed, reproduction error was found to be greater in the kinaesthetic than the visual modality, and in distance as compared with location strategy conditions Moreover, there was no significant Modality x Strategy interaction. These findings support hypothesis 1, that, for both distance and location strategies, error will be greater in the kinaesthetic than the visual modality. This is consistent with the finding in Experiment 3 that error was greater when the standard stimulus was presented in the kinaesthetic, as compared with the visual modality, and with the suggestion in Chapter 4 that this difference can be attributed to information in the kinaesthetic modality being less precise than in the visual modality. Also, these findings support hypothesis

2, that for both modalities error will be greater when a distance, as compared with a location strategy, is used.

Reproduction accuracy was found to improve between the ages of 10 and 12 years. However, hypothesis 3, that for judgements of location in the kinaesthetic modality, and of both distance and location in the visual modality, accuracy will improve with age, but there will be little or no improvement for judgement of distance in the kinaesthetic modality, was not supported. The results showed similar improvements in accuracy with age for judgements of distance in both the visual and kinaesthetic modalities, and for judgements of location in the kinaesthetic modality. However, there was no improvement in accuracy for judgements of distance in the visual modality. Since in both the Connolly and Jones (1970) and Hulme et al. (1983) studies reproduction accuracy for judgements of distance in the visual modality were found to improve with age, the absence of a between-group difference for the VVD conditions in the present experiment is surprising. The most likely explanation is that this finding can be attributed to the small age range involved once the 8-year-old children were excluded.

On the other hand, since it has been argued that kinaesthesis is not suitable for accurate judgements of movement distance, the finding of a between-group difference in the KKD condition is also surprising. The most likely explanation is that, because kinaesthesis is not suitable for such judgements, subjects judged movement distance on the basis of the distance between the start and end-points of the movement, i.e. on the basis of location. Although resulting in error, because of the offset between start-points for presentation and reproduction lines, judgements of both the standard stimulus and reproduction movement could be made on the basis of judgements of location in the kinaesthetic modality. Since the present findings show a between-group improvement in accuracy for judgements of location in the kinaesthetic modality, the use of this strategy could explain the finding of a similar improvement in the KKD condition.

Consistent with the earlier findings of Connolly and Jones (1970) and Hulme et al. (1983) studies, then, the present results suggest that in both modalities perceptual ability develops during childhood. However, although the results clearly suggest an improvement in the ability to make judgements of location in both modalities, the findings for judgements of distance in the both modalities are questionable.

When data for the 8-year-old children were included in the analysis, the pattern of correlations with motor ability supports hypothesis 4, that there will be a strong correlation between motor ability and accuracy of judgement of location in the kinaesthetic modality, and of both distance and location in the visual modality, but a low correlation with accuracy of judgement of distance in the kinaesthetic modality. However, when data for the 8-year-old children were excluded this hypothesis was not supported, correlations with motor ability for all conditions being significant. Moreover, no significant difference was found between correlations in the VVD and KKD conditions, or the VVL and KKL conditions. As has already been pointed out, it was evident that the 8-year-old children had difficulty understanding the concept of reproducing movement distance, as contrasted with location, in the kinaesthetic modality, and the low correlation found for the KKD condition in the initial analysis can be attributed to this.

The similarity between correlations, when data for the 8-year-old children were excluded, suggests that ability to judge distance and location in both modalities contributes to motor ability. However, since it has been suggested that in the KKD condition subjects may have based judgements of movement distance on the start and end-points of the movement, i.e. using location information, the finding of a moderately strong correlation between motor ability and accuracy in judgement of distance in the kinaesthetic modality is equivocal. Hulme et al. (1983) similarly found moderately strong correlations between motor ability and reproduction accuracy in both their VV and KK conditions. Nonetheless, although Hulme and his colleagues instructed their subjects to reproduce the length of the standard stimulus, it is possible that their subjects used a location strategy in their KK condition. Alternatively, it is possible that, as suggested here, their subjects based judgements of movement distance on the location of the start and end-points of the movement. The contribution to motor skill of ability to judge distance in the kinaesthetic modality therefore remains unresolved.

EXPERIMENT 5

Motor Ability and Translation

When translation between the visual and kinaesthetic modalities was required in Experiment 3, reproduction error was greater for presentation in the kinaesthetic modality, and this was attributed to a comparative lack of precision of information in this modality. Further, error was greater when a distance, as compared with a location strategy, was used and this was attributed to judgements of distance in both modalities being more difficult than judgements of location. Consistent with these suggestions, in Experiment 4 error was greater in the kinaesthetic than the visual modality, and when a distance as compared with a location strategy was used, for within-modal reproduction tasks. It can be expected, therefore, that for reproduction tasks requiring translation between modalities, error will be greater both when the standard stimulus is presented in the kinaesthetic modality and when a distance strategy is used.

The findings of Experiment 4, together with those of Connolly and Jones (1970) and Hulme et al. (1983), suggest that, during childhood, there is an improvement in perceptual ability in both modalities. Connolly and Jones found that reproduction accuracy in translation tasks also improved with age. Further, Hulme et al. (1983) found similar improvements in within-modal and translation tasks, concluding that improved accuracy in translation tasks can be attributed to the development of perceptual ability. However, as was pointed out in Chapter 2, findings for translation tasks have been inconsistent and Goodnow (1971) has suggested that this may be attributable to differences in the nature of information. Distance and location strategies involve the use of information in different forms, and so variations in reproduction accuracy for translation tasks could result from differences in strategy. In particular, it was argued in Chapter 4 that, because kinaesthesis is not suitable for judgements of movement distance, when a distance strategy is used in translation tasks a loss of accuracy will result. By comparison, it was argued that, because both vision and kinaesthesis are suitable for judgements of location, when a location strategy is used there will be no comparable loss of accuracy. Consistent with this suggestion, in Experiment 3 reproduction error was found to be greater in both the VK and KV conditions when a distance, as compared with a location strategy, was used.

In Experiment 4 reproduction accuracy in within-modal tasks was found to improve with age when a location strategy was used and similar improvement is expected, therefore, when a location strategy is used in translation tasks. On the other hand, since kinaesthesis is not suitable for judgements of movement distance, and this would be expected to be so at all ages, accuracy in judgements of distance in the kinaesthetic modality should not improve with age. Although Experiment 4 found improved accuracy with age for judgement of distance in the kinaesthetic modality, this may have resulted from subjects basing judgements of distance on the location of the start and end-points of the movement. This would allow for judgements of both the standard stimulus and reproduction movements to be made on the basis of judgements of location in the kinaesthetic modality. However, when a distance strategy is used in translation tasks, since either the standard stimulus or reproduction line is presented in the visual modality, this strategy would be difficult to use, and so it is likely that subjects will be unable to judge movement distance on the basis of location judgements. Therefore, because kinaesthesis is not suitable for judgements of distance, when a distance strategy is used in translation tasks there should be no improvement in accuracy with age.

Again, as for within-modal perception, it would be expected that improvement in translation ability should be accompanied by an improvement in motor ability. In Experiment 4 moderately strong correlations were found between reproduction accuracy in both modalities and motor ability when a location strategy was used in within-modal tasks. Therefore, it would be expected that, for a location strategy in a translation task, a moderately strong correlation between accuracy and motor ability should also be found. However, it has been argued that kinaesthesis is not suitable for judgements of movement distance and, when a distance strategy is used in translation tasks, judgements of either the standard stimulus or reproduction movement are required. Although in Experiment 4 a moderately strong scorrelation was found between accuracy of judgement of movement distance in the kinaesthetic modality and motor ability, this can possibly be attributed to subjects having based judgements on location of the movement start and end-points. Moreover, it has been argued that subjects will be unable to use a distance strategy in translation tasks. Therefore, when a distance strategy is used in translation tasks a low correlation between reproduction accuracy and motor ability should result.

In summary, this experiment was designed to test the hypotheses that, when a translation between modalities is required:

1. For both distance and location strategies, error will be greater when the standard stimulus is presented in the kinaesthetic, as compared with the visual modality.
2. Error will be greater when a distance, as compared with a location strategy, is used.
3. Reproduction accuracy will improve with age for judgements of location, but not of distance.
4. There will be a strong correlation between motor ability and reproduction accuracy when a location strategy is used, but not when a distance strategy is used.

Method

Subjects and Apparatus

The subjects and apparatus were the same as in Experiment 4. Although in Experiment 4 the 8-year-old group had difficulty with understanding the experimental tasks in the kinaesthetic modality, it was thought that, because of the inclusion of either a visual line or a spot of light, as appropriate to strategy, they might find judgements of distance and location in the kinaesthetic modality easier to understand in translation tasks.

Experimental Tasks

This experiment was essentially a replication of Experiment 4, with the exception that tasks requiring the translation of information between modalities were used. Subjects were presented with standard stimulus line lengths (D), or locations (L) in either the visual (V) or kinaesthetic (K) modality, which they were required to reproduce in the other modality. This resulted in four experimental conditions: VKD, KVD, VKL and KVL.

Procedure

With the exception of the explanation of the experimental tasks, the procedure followed in this experiment was identical to that used in Experiment 4.

Results

Residual Error

Residual error scores are shown in Appendix 5.7. As in Experiment 4, to investigate the possibility of a differential effect of sex, these data were analyzed using a 2(Sex) x 3(Age) x 2(Presentation Modality) x 2(Strategy) analysis of variance with repeated measures on the last two factors (see Appendix 5.8). Mean error for boys (18 mm) was greater than that for girls (16 mm), $F(1, 30) = 5.65$, $p<.05$, but no interactions involving Sex were significant. Sex, therefore, was disregarded and the data were collapsed over this factor.

The resulting residual error scores were analyzed using a mixed design, 3(Age) x 2(Presentation Modality) x 2(Strategy) x 5(Length) analysis of variance with specific effects of length analyzed as planned comparisons of trend (see Appendix 5.9). The main effect of Age ($F(2, 33) = 5.91$, $p<.01$) and the linear trend of Length ($F(1, 132) = 32.67$, $p<.001$) were significant. The main effect of Strategy was not significant, $F(1, 33) = 0.01$, $p>.05$, but there was a significant Age x Strategy interaction, $F(2, 33) = 4.88$, $p<.05$, and a significant Age x Strategy x Length interaction for the linear trend of length, $F(2, 132) = 4.47$, $p<.05$. Mean error scores, collapsed over modality, are shown in Figure 5.5. Accuracy improved with increase in age, mean error decreasing from 19.6 to 15.9 to 15.1 mm, but that the pattern of error differed with age. Figure 5.5 shows that, as in Experiment 4, error for the 8-year-old group increased with length in both the location and distance strategy conditions; but for the 10 and 12-year-old groups error increased with length to a greater extent in the distance than the location strategy conditions.

It was therefore evident that, as before, the 8-year-old children had not used distance and location strategies as instructed. The scores for these children were again deleted and the data for the 10 and 12-year-old children re-analyzed (see Appendix 5.10). This analysis revealed that there was no significant difference in mean error either between the 10-year-old (15.94 mm) and 12-year-old (15.09 mm) groups, $F(1, 22) = 0.45$, $p>.05$, or between the distance (16.23 mm) and location (14.80 mm) strategy conditions, $F(1, 22) = 3.36$, $p>.05$. However, there was a significant effect for the linear trend of Length, $F(1, 88) = 8.16$, $p<.01$, and a significant Strategy x Length interaction for the linear trend of length, $F(1, 88) = 3.98$. $p<.05$. Mean residual error scores, collapsed over age and modality, are

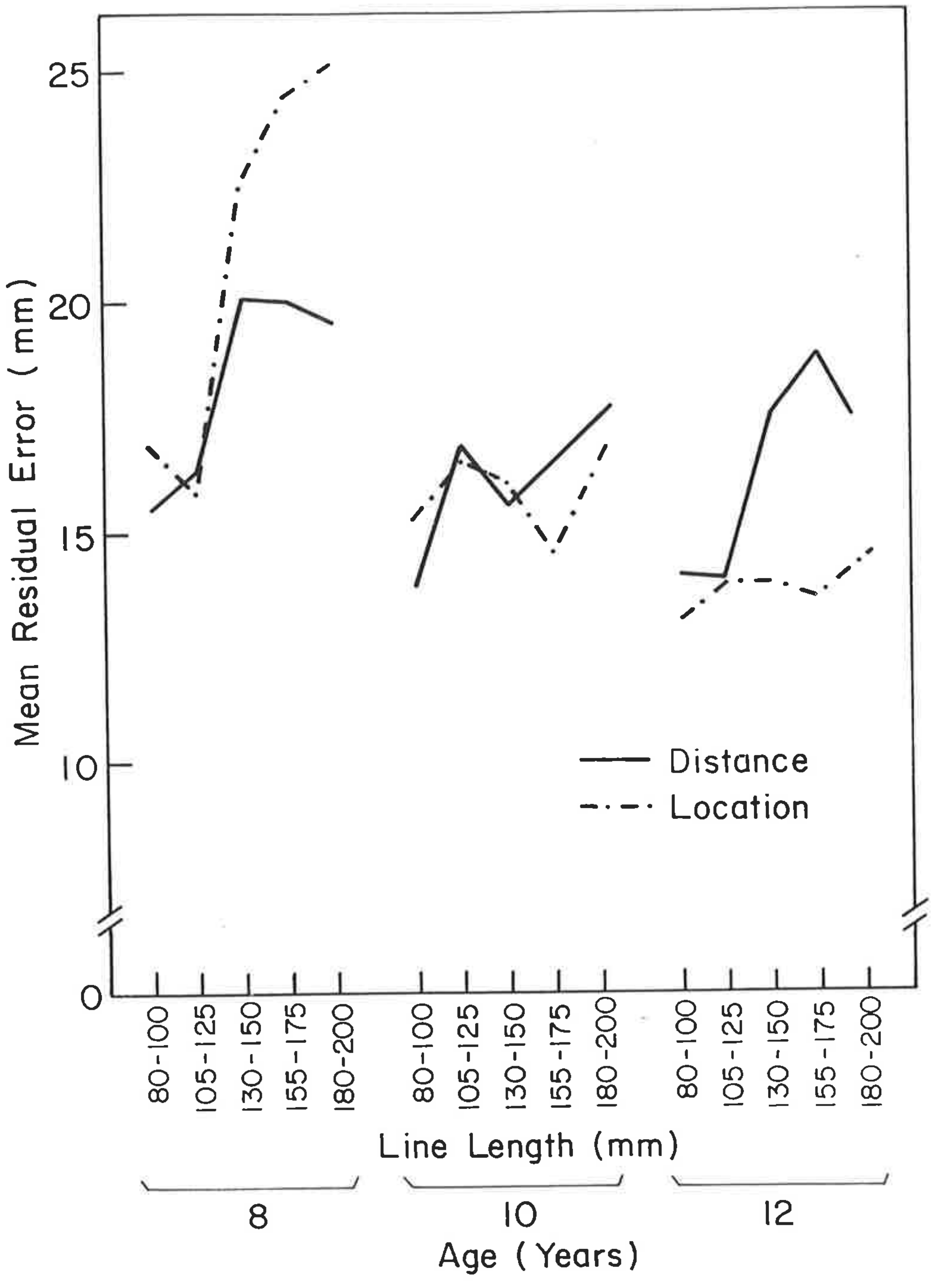


FIGURE 5.5: Residual Error (collapsed over modality) for. 8, 10 and 12-year-old children in Experiment 5

shown in Figure 5.6. The result for Experiment 4 was replicated, residual error increasing with the length of the standard stimulus in distance strategy conditions, but remaining relatively constant in location strategy conditions.

When a distance strategy was used there was little difference between mean residual error for the 10-year-old group (16.1 mm) and the 12-year-old group (16.4 mm). By comparison, when a location strategy was used mean error for the 10-year-old group (15.8 mm) was greater than that for the 12-year-old group (13.8 mm). However, the Age x Strategy interaction was not significant, $F(1, 22) = 2.24$, $p>.05$.

There was no significant difference between mean error for presentation of the standard stimulus in the visual (14.79 mm) and kinaesthetic (16.24 mm) modalities, $F(1, 22) = 2{,}68$, $p>.05$. However, there was a significant Modality x Length interaction for the linear trend of length, $F(1, 88) = 9.45$, $p<.005$, and a significant Age x Modality x Length interaction, $F(4, 88) = 2.56$, $p<.05$. An examination of the data revealed that for the 12-year-old group error increased with length in both modalities, whereas for the 10-year-old group error increased with length only in the kinaesthetic modality. However, the size of the effect was small.

Correlations

As in Experiment 4, Pearson product moment correlations were calculated between motor ability scores and residual error. Again, higher motor ability scores were associated with lower error scores, resulting in negative correlations.

Although the pattern of residual error showed that the 8-year-old children had not used distance and location strategies as instructed, the scores for the children in this group were included in the initial analysis so as to use the maximum available range of abilities. The resulting

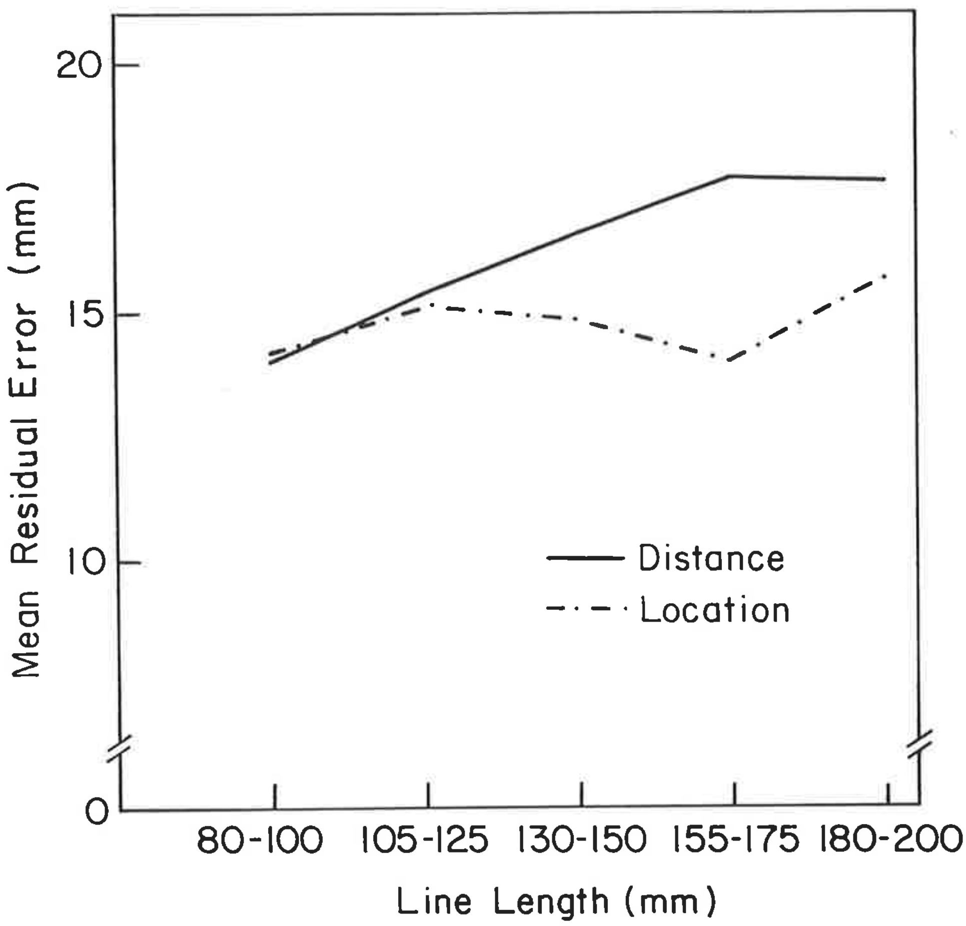


FIGURE 5.6: Residual Error (collapsed over age and modality) for 10 and 12-year-old children in Experiment 5

correlations are shown in Table 5.4. This Table shows that for both distance strategy conditions correlations were comparatively low whereas those for both location strategy conditions were higher. Comparisons using Ferguson's (1966) procedure found no significant difference between correlations for the VKL and VKD conditions, $t(33) = 0.71$, $p>.05$, but the correlation for the KVL condition was significantly larger than that for the KVD condition, $t(33) = 2.39$, $p<.05$.

Table 5.4

Correlations Between Motor and Residual Error Scores in Experiment 5 for 8, 10 and 12-year-old Children

	r	*p*
VKD	-.32	<.05
KVD	-.33	<.05
VKL	-.44	<.005
KVL	-.67	<.001

Scores for the 8-year-old children were then deleted from the data and correlations were calculated between motor ability and residual error scores for the 10 and 12-year-old children. The resulting correlations are shown in Table 5.5. For both groups, correlations in both distance strategy conditions were low and not significant, but those for both location strategy conditions were higher and significant. However, paired comparisons found no significant differences.

Table 5.5

Correlations Between Motor and Residual Error Scores in Experiment 5 for 10 and 12-year-old Children

	r	*p*
VKD	-.24	>.05
KVD	-.16	>.05
VKL	-.44	<.05
KVL	-.47	<.05

Discussion

For the 10 and 12-year-old groups, mean residual error increased with the length of the standard stimulus to a greater extent in distance, as compared with location strategy conditions. Again, this pattern is similar to that observed by Hermelin and O'Connor (1973) and Salmoni and Sullivan (1976) for their distance and location strategy conditions, and particularly, for residual error in Experiments 3 and 4 in location and distance strategies. The present findings, therefore, suggest that the 10 and 12-year-old children followed the experimenter's instructions to use distance and location strategies, but the 8-year-olds did not.

When the data for the 10 and 12-year-old groups were analyzed, although residual error was found to be greater when the standard stimulus was presented in the kinaesthetic, as compared with the visual modality, the difference was not statistically significant. Therefore, hypothesis 1, that for both distance and location strategies, error will be greater when the standard stimulus is presented in the kinaesthetic, as compared with the visual modality, was not supported. Similarly, although residual error was greater in distance than location strategy conditions, the difference was not statistically significant. Therefore, hypothesis 2, that error will be greater when a distance, as compared with a location strategy is used, also was not supported.

These findings are inconsistent with those of Experiment 3, in which greater error was found for translation tasks both when the standard stimulus was presented in the kinaesthetic modality and when a distance strategy was used. Since the subjects in Experiment 3 were adults, whereas those in the present experiment were children, this disparity could be attributed to age difference. However, the present findings are also inconsistent with those of Experiment 4, in which error was found to be greater both in the kinaesthetic modality and when a distance strategy was used for within-modal tasks. Since the subjects in Experiment 4 and the present experiment were the same children, this disparity cannot be attributed to an age difference.

The only difference between Experiment 4 and 5 was the requirement to translate information between modalities, suggesting that the failure to support hypotheses 1 and 2 is associated with this requirement. Hulme et al. (1983) found no differential improvement with age for reproduction accuracy in within-modal and translation tasks, and concluded that translation ability is determined by perceptual development. However, as was discussed in Chapter 2, the findings of studies in which the translation of information between modalities is required have been inconsistent. The results of Experiments 1 to 3 show that several factors can affect the outcome of experiments following the Connolly and Jones (1970) design. Further, in Experiment 4 the between-group difference for accuracy in within-modal judgements was significant, whereas in

Experiment 5 the between-group difference in translation tasks was not. This suggests that, between the ages of 10 and 12 years, translation ability develops more slowly than does within-modal perception. This is consistent with the Jackson (1973) finding that, between the ages of 6 and 10 years, accuracy in judgement of shape improved more in within-modal than in translation conditions. If translation ability develops more slowly than within-modal perception, then the difference in translation ability between children of different ages would be expected to be less than that in within-modal perceptual development. Moreover, because of normal variation, it would be expected that, in some individuals, translation ability will develop more rapidly than in others. Thus, the age difference here of only two years may account for the failure to support hypotheses 1 and 2 in the present experiment.

Although there was little between-group difference in error when a distance strategy was used, error was greater for the 10-year-old than the 12-year-old children when a location strategy was used. However, the Age x Strategy interaction was not significant. Therefore, hypothesis 3, that reproduction accuracy will improve with age for judgements of location, but not of distance was not supported. Once more, the failure to support this hypothesis is likely to be attributable to the small age difference between subjects.

With 8-year-old children excluded, no significant difference in correlations was found between either the VKD and VKL conditions, or the KVD and KVL conditions. Detterman (1989) suggests that, in correlational research, samples of less than 100 are relatively small, and he comments that larger samples are required for the power needed to detect significant differences between correlations unless the difference is large. For example, he finds that a sample of about 200 is needed to find a significant difference between correlations of .30 and .50. The absence of significant differences between the present correlations, therefore, can be attributed to the relatively small sample size used.

Nonetheless, correlations in the VKL and KVL conditions were higher than those in the VKD and KVD conditions. Moreover, the former correlations were statistically significant, whereas the latter were not. Therefore, although equivocal, the pattern of correlations observed supports hypothesis 4, that there will be a strong correlation between motor ability and reproduction accuracy when a location strategy is used, but not when a distance strategy is used. Subjects in the Hulme et al. (1983) study were required to reproduce the standard stimulus length and low correlations between reproduction accuracy and motor ability were also found in their translation conditions. The present findings, together with those of Hulme et al. (1983), therefore support the suggestion that, because kinaesthesis is not suitable for accurate judgements of distance, the translation of distance information will not contribute to motor ability. Further, the present findings of statistically significant correlations between reproduction accuracy and motor ability when a location strategy was used, support the suggestion that, because both modalities are suitable for judgements of location, the translation of location information between modalities will contribute to motor ability.

General Discussion

The results of Experiments 4 and 5 show that, when subjects are required to reproduce a standard stimulus, accuracy can be expected to be affected by both modality and strategy. In Experiment 4 reproduction error was greater in the kinaesthetic than the visual modality, and in distance as compared with location strategy conditions. When a translation between modalities was required in Experiment 5, error was similarly greater when the standard stimulus was presented in the kinaesthetic modality and when a distance strategy was used, but these differences were not statistically significant. However, a comparison between Experiments 4 and 5 suggests that the translation process develops more slowly than within-modal perception, and it was suggested that the absence of significant between-group differences for modality and strategy in Experiment 5 could be attributable to the slower development of the translation process, together with normal variation in rate of development, resulting in reduced between-group differences.

Further, the findings of Experiments 4 and 5 show that correlations between motor ability and reproduction accuracy are also affected by modality and strategy. In Experiment 4 significant correlations were found between motor ability and accuracy of judgement of distance and location in both modalities, although the findings for judgements of distance in the kinaesthetic modality were equivocal. When a translation between modalities was required in Experiment 5, significant correlations were found between motor ability and accuracy in judgements of location. However, low and nonsignificant correlations were found for judgements of distance. This finding was attributed to kinaesthesis being unsuitable for accurate judgements of movement distance. The results of Experiment 5 therefore suggest that ability to transfer location information between modalities contributes to motor ability, but that ability to translate distance information does not. It is possible, then, that differences in strategy used by subjects could have affected the outcome of earlier experiments of this type.

An interesting finding was that the 8-year-old children in Experiments 4 and 5 had difficulty with understanding the requirements of the experimental tasks when judgement of distance in the kinaesthetic modality was involved. This was evident in Experiment 4, in which it was clear that these children had difficulty with the concept of reproducing movement distance, as contrasted with location, in the kinaesthetic modality. Moreover, the error pattern in both experiments revealed that the 8-year-old children had not used distance and location strategies as instructed. It is likely, then, that in earlier studies in which children of this age or younger were tested, the outcome was affected by similar difficulties.

Because of the problems experienced by the 8-year-old children, in both experiments the data for this group were excluded from the final analyses, thereby markedly reducing sample size and age range. It is likely that the failure to find an improvement in accuracy with age for judgements of distance in the kinaesthetic modality, and of a differential improvement with age in distance as compared with location strategies in translation tasks, can be attributed to the small difference in the ages of subjects.

It could be suggested that the outcome of these experiments was affected by the ability of subjects to control their movements, rather than perceptual ability, but the results were not consistent with this. If reproduction accuracy were determined by the ability of subjects to control their movements, then correlations between motor ability and reproduction accuracy would be larger for reproduction in the kinaesthetic than the visual modality. However, in both experiments correlations for visual and kinaesthetic reproduction were similar in magnitude. As in the Hulme et al.

(1982, 1983) studies, therefore, the patterns of correlations observed in the present experiments provide no support for the suggestion that the outcome was determined by motor control.

A further possible criticism is that correlations between perceptual and motor abilities do not reflect a causal relationship. However, as is shown by a number of studies discussed in Chapter 2, perception in both the visual and kinaesthetic modalities is important in the performance of motor skills. Therefore, a strong relationship between perceptual and motor abilities, and between translation and motor abilities, would be expected. Further, the correlations observed in Experiments 4 and 5 were in the expected direction and, with the exception of the correlation found for the KKD condition in Experiment 4, the patterns of correlations were as predicted on theoretical grounds. Moreover, if the correlations observed were the result of some third factor, it would be difficult to explain the differences in pattern of correlations observed between Experiments 4 and 5, and between strategies in Experiment 5. Nonetheless, the evident difficulty experienced by the 8-year-old children with understanding tasks involving judgements of movement distance in the kinaesthetic modality, shows that performance in experiments of this design can be affected by cognitive factors.

CHAPTER 6
PERCEPTION, TRANSLATION AND IMPAIRED MOTOR SKILL

The importance of perception in the control of skilled movements was discussed in Chapter 2, and it was suggested that abnormal clumsiness in children could be attributable to a perceptual defect in either the visual or the kinaesthetic modality. It was also suggested that a defect in the ability to translate information between modalities could be involved. Therefore, the approach to the investigation of abnormal clumsiness adopted by Hulme et al. (1982a, 1983, 1984) is valuable, because it allows for the assessment of perception in both modalities, and of the translation process. However, the results of Experiments 1 to 5 show that several factors can affect the outcome of experiments in which subjects are required to reproduce a standard stimulus. In particular, the findings of these experiments show that both modality and suitability of modality to strategy can affect reproduction accuracy. Moreover, the findings of Experiments 4 and 5 show that correlations between motor ability and reproduction accuracy can be similarly affected. It is possible, then, that the outcome of the Hulme et al. (1982a, 1983, 1984) studies could have been affected by these factors.

Although in experiments of this design subjects are instructed to reproduce the length of a standard stimulus, it was argued in Chapter 3 that they can use either a distance or a location strategy. Further, it was suggested in Chapter 5 that judgements of distance are more difficult than judgements of location and, consistent with this, in Experiment 4 greater error was found for within-modal tasks in both the visual and kinaesthetic modalities when a distance, as compared with a location strategy, was used. It would, therefore, be expected that, when free to do so, subjects will use a location strategy. Moreover, it was argued in Chapter 3 that kinaesthesis is not suitable for accurate judgements of movement distance, but is suitable for judgements of location. Consequently, it would be expected that subjects will use a location strategy when the standard stimulus is presented in the kinaesthetic modality. Consistent with this, the results of Experiment 2 suggest that, although instructed to reproduce length, when the standard stimulus was presented in the kinaesthetic modality, subjects used a location strategy. Subjects can, however, use a distance strategy and the findings of the Hermelin and O'Connor (1975) and Salmoni and Sullivan (1976) studies, and of Experiments 3, 4 and 5, show that subjects can be forced to do so. Although, then, in the Hulme et al. (1982a, 1983, 1984) studies subjects were instructed to reproduce the length of the standard stimulus, their subjects could have used either a distance or a location strategy.

Hulme et al. (1982a) tested the perceptual ability of 16 clumsy children and found that they were less accurate than their controls when reproducing standard stimulus lengths within both the visual and kinaesthetic modalities. Subsequently, Hulme et al. (1982b) investigated the ability of 12 of the clumsy children and their controls to reproduce the length of a visual standard stimulus line, which was present alongside the reproduction line, and to decide which of a pair of lines, presented simultaneously and side by side using a tachistoscope, was the longer. Again, in both of these experiments the clumsy children were found to be less accurate than their controls. Further, Hulme et al. (1984) compared the performance of their sixteen 10-year-old clumsy children with that of a group of 6-year-old normal children who had comparable motor ability. In this experiment no significant between-group difference in reproduction accuracy was found for within-modal judgements. Thus the findings of these studies suggest that abnormal clumsiness is associated with a defect in the development of perception in both modalities.

In addition, Hulme et al. (1982a) found that their 16 clumsy children were also less accurate than their controls when reproducing standard stimulus lengths and a translation of information between modalities was required. Further, they found that reproduction was less accurate in translation than in within-modal conditions, but that this was equally so for both clumsy and control groups. This finding suggests that abnormal clumsiness in children is not associated with a defect of the translation process, and that the greater reproduction error found for clumsy children in translation conditions can be attributed to their evident perceptual defect.

It has already been suggested that, although instructed to reproduce the length of the standard stimulus, because kinaesthesis is not suitable for judgments of movement distance it is unlikely that subjects will use a distance strategy in this modality unless forced to do so. Moreover, since vision is suitable for judgements of distance, but kinaesthesis is not, if a distance strategy is used for within-modal judgements in both modalities, reproduction error will be greater for judgements in the kinaesthetic than the visual modality. On the other hand, since both modalities are suitable for judgements of location, if a location strategy is used in both within-modal conditions no loss of accuracy attributable to unsuitability of modality to strategy will result in either. In the Hulme et al. (1982a) experiment no significant difference in accuracy was found between within-modal conditions. This finding, then, suggests that the children in that experiment used a location strategy in both within-modal conditions.

In Chapter 4 it was argued that the asymmetry observed between accuracy in translation conditions by Connolly and Jones (1970), and other investigators, can be attributed to differences in strategy, together with suitability of modality to strategy. It was argued that, because kinaesthesis is not suitable for judgements of movement distance, when a distance strategy is used a loss of accuracy will result, whereas since both modalities are suitable for judgements of location, when a location strategy is used there will be no loss of accuracy due to unsuitability of modality to strategy. Consistent with this reasoning, in Experiment 3 greater error in both translation conditions was found when a distance, as compared with a location strategy, was used.

Hulme et al. (1982a) found no difference in accuracy between translations from vision to kinaesthesis and from kinaesthesis to vision. This finding, therefore, suggests that the children in that experiment used the same strategy in both translation conditions. Further, Hulme and his colleagues found that error in translation conditions was greater than in within-modal conditions. If the children in this experiment used a location strategy in both within-modal and translation conditions, this difference could be attributed to the loss of accuracy associated with the translation of information between modalities suggested by Connolly and Jones (1970). Moreover, if the children used a location strategy in within-modal conditions, but a distance strategy in translation conditions, a difference between within-modal and translation conditions would be expected as a result of the loss of accuracy attributable to the unsuitability of kinaesthesis for judgments of movement distance. Although, then, the pattern of error suggests that the same strategy was used in both translation conditions, the strategy used cannot be determined on the basis of error pattern.

When correlations between reproduction accuracy and motor ability were calculated in the Hulme et al. (1982a) experiment, a moderately strong correlation was found for within-modal judgements in the visual ($r = -.62$, $p<.01$), but not the kinaesthetic ($r = -.34$, $p>.05$) modality. By comparison, Hulme et al. (1983) found moderately strong correlations for within-modal judgements in both the visual ($r = -.56$, $p<.001$) and kinaesthetic ($r = -.59$, $p<.001$) modalities. Moreover, for the 10 to 12-year-old children in Experiment 4 similar correlations between reproduction accuracy and motor ability were found for judgements of location in both the visual ($r = -.40$, $p<.05$) and kinaesthetic ($r = -.54$, $p<.005$) modalities, and for judgements of distance in both the visual ($r = -.47$, $p<.05$) and kinaesthetic ($r = -.45$, $p<.05$) modalities. Although these correlations were somewhat lower than those found in the Hulme et al. (1983) study, this is likely to be attributable to the small difference in age, and hence in abilities, between the children in Experiment 4. Since clumsy children were included only in the Hulme et al. (1982a) experiment, it is possible that the low correlation found for judgements of distance in the kinaesthetic modality in that experiment could be attributed to the inclusion of this group. However, Hulme and his colleagues found low correlations between reproduction accuracy and motor ability for both their clumsy ($r = -.13$) and normal ($r = -.03$) children. There is, then, no apparent explanation for these low correlations.

Hulme et al. (1982a) do not report the values of correlations between motor ability and reproduction accuracy in their translation conditions, but they comment that they were not statistically significant. In the Hulme et al. (1983) experiment, however, correlations for translation of information from the visual to kinaesthetic modality ($r = -.35$, $p<.05$) and from the kinaesthetic to the visual modality ($r = -.24$, $p.>05$) were both low.

Similarly, low correlations were found for the 10 to 12-year-old children in Experiment 5 for the translation of distance information from the visual to the kinaesthetic modality ($r = -.24, p > 05$) and from the kinaesthetic to the visual modality ($r = -.16, p > .05$). Higher correlations, by comparison, were found in Experiment 5 for the translation of location information from the visual to kinaesthetic modality ($r = -.44, p < .05$) and from the kinaesthetic to the visual modality ($r = -.47, p < .05$). The finding of lower correlations for the translation of distance information between modalities in Experiment 5 was attributed to the unsuitability of kinaesthesis for judgements of movement distance. Therefore, since in the Hulme et al. (1982a, 1983) experiments subjects were instructed to reproduce the length of the standard stimulus, the low correlations found in these experiments for translation conditions could be similarly explained.

Although, then, Hulme et al. (1982a) instructed the children in their experiment to reproduce the length of the standard stimulus, the pattern of error suggests that in within-modal conditions a location strategy was used. On the other hand, the pattern of correlations found between reproduction accuracy and motor ability suggests that in translation conditions their subjects used a distance strategy. Why the children in this experiment would use a location strategy in within-modal conditions, but comply with the experimenter's instructions and use a distance strategy in translation conditions, is not clear.

If the children in the Hulme et al. (1982a) experiment used a location strategy in within-modal conditions, the finding of greater error for judgements in both the visual and kinaesthetic modalities suggests that abnormal clumsiness is associated with a perceptual defect affecting ability to judge location, which is not modality specific. By comparison, since in the Hulme et al. (1982b) study the standard stimulus and reproduction lines were side by side, a location strategy could not have been used. Consequently, the finding of greater error for the clumsy group in this study strongly suggests that clumsiness is associated with a perceptual defect in the visual modality affecting ability to judge distance.

A further finding in the Hulme et al. (1982a) experiment was a moderately strong correlation ($r = .60, p<.001$) between motor ability and performance IQ (PIQ), as measured by the Wechsler Intelligence Scale for Children (WISC). Moreover, whereas no significant difference was found between clumsy and control children for verbal IQ (VIQ), the PIQ of the clumsy group was significantly lower than that of their controls. Since the performance subscales of the WISC involve visual perception, this finding adds support to the suggestion that abnormal clumsiness is associated with a visual perceptual defect.

Although, the clumsy children in the Hulme et al. (1982a) experiment were less accurate in translation conditions than were their controls, both clumsy and control children were less accurate in translation than in within-modal conditions and the loss of accuracy was similar for both groups. This finding therefore provides no support for an association of clumsiness with a defect of the translation process. However, Hulme and his colleagues found low correlations between reproduction accuracy and motor ability for both translation conditions and, if their subjects used a distance strategy in these conditions, these low correlations can be attributed to the unsuitability of kinaesthesis for judgements of distance. Moreover, kinaesthesis is not suitable for judgements of distance and this would be expected to be so for all children. Consequently, no differential improvement in the translation of distance information between modalities would be expected. The absence of support for an association of a defect of the translation process with clumsiness in the Hulme et al. (1982a) experiment could be attributable, therefore, to the use of a distance strategy in their translation conditions.

EXPERIMENT 6

Judgements of location are important in the performance of motor skills, and it was argued in Chapter 5 that both modalities are suitable for such judgements. Therefore, in both modalities, accuracy in judgement of location should contribute to motor skill. Consistent with this view, when a location strategy was used in Experiment 4 correlations between motor ability and reproduction error were found for judgements of location in both the visual ($r = -.40, p<.05$) and kinaesthetic ($r = -.54, p<.005$) modalities. Further, ability to translate location information between modalities should also contribute to motor skill. Consistent with this view, when a location strategy was used in Experiment 5 and the translation of information between modalities was required, a correlation between motor ability and reproduction error was found for the translation of location information from vision to kinaesthesis ($r = -.44, p<.05$), and from kinaesthesis to vision ($r = -.47, p<.05$). The results of Experiments 4 and 5, therefore, suggest that ability to judge location in the visual and kinaesthetic modalities, and to translate location information between modalities, both contribute to motor ability and a defect in either ability would be expected to result in impaired motor skill.

The findings of Hulme et al. (1982a) suggest that clumsiness is associated with a perceptual defect in the visual modality, although it is not clear whether the subjects in that experiment used a distance or a location strategy. However, the findings of Hulme et al. (1982b) strongly suggest that abnormal clumsiness is associated with a perceptual defect that impairs ability to judge distance in the visual modality, and the results of the Hulme and Lord (1987) study indicate a more general perceptual defect in this modality. It would be expected, then, that clumsy children would experience difficulty with judgment of location in the visual modality. The Hulme et al. (1982a) results also suggest that a perceptual defect in the kinaesthetic modality is associated with clumsiness, although again, it is not clear whether the subjects in that experiment used a distance or a location strategy. This is consistent with the Smyth and Glencross (1982, 1986), Laszlo et al. (1988) and Bairstow and Laszlo (1989) findings discussed in Chapter 2, which suggest an association of clumsiness with a defect in the kinaesthetic modality. Therefore, it would also be expected that clumsy children would experience difficulty with judgment of location in the kinaesthetic modality.

It was also suggested in Chapter 2 that clumsiness might be associated with a defect in the translation of information between modalities. Although Hulme et al. (1982a) found that accuracy was lower in translation than in within-modal conditions, this can be attributed to the loss of accuracy associated with translation suggested by Connolly and Jones (1970). Moreover, Hulme and his colleagues found no differential effect of translation on clumsy, as compared with control children, and only low correlations between accuracy in translation conditions and motor ability. However, these findings may be attributable to the children in that experiment having used a distance strategy in translation conditions, together with the unsuitability of kinaesthesis for accurate judgements of movement distance that is common to all children. On the other hand, since both modalities are suitable for judgements of location, when the translation of location information is required, although a loss of accuracy would be expected, any defect of the translation process would not be masked by unsuitability of modality to strategy. Therefore, if clumsiness is associated with a defect in the translation process, there should be a loss of accuracy which is greater for clumsy, as compared with control children.

In summary, this experiment was designed to test the hypotheses that:

1. For judgements of location in the visual modality, clumsy children will be less accurate than control children.
2. For judgements of location in the kinaesthetic modality, clumsy children will be less accurate than control children.
3. The loss of accuracy, associated with the translation of location information between modalities, will be greater for clumsy children than for control children.

Method

Subjects

Subjects in this experiment were 15 clumsy[1] children and 15 controls, matched for sex and age. There were 11 boys and four girls in each group. The mean age of the clumsy children was 9 years 3 months (range 7-7 to 10-8) and that of the control children was 9 years 3 months (range 7-8 to 10-6)[2].

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1. Although it was suggested in Chapter 1 that these children could be more appropriately described as "motor impaired", the term "clumsy" has been used here to avoid confusion when referring to earlier studies.

2 Because it was evident in Experiments 4 and 5 that the 8-year-old children had difficulty with understanding the experimental tasks, an attempt was made to exclude younger children from this experiment. However, the age range of subjects tested was restricted by the availability of clinically identified clumsy children. This also limited the sample size.

Clumsy children were enrolled in remedial programmes for motor skill difficulties.[3] None of these children suffered from any identifiable physical problem to which impaired motor skill could be attributed. Although the children had been clinically identified as clumsy, to confirm their impaired motor skill they were tested using the Gubbay (1989) test. As an operational definition, a clumsy child was considered to be one who failed on two or more items of this test. One additional boy passed all items and was discarded from the sample. Also, to ensure that motor impairment was not associated with an intellectual disability, the children's intelligence was assessed using the Wechsler Intelligence Scale for Children (WISC-R). One additional girl was also discarded from the sample because of her low verbal IQ (VIQ) (60), and marked disparity between her verbal and performance IQ (PIQ) (98). The control group was comprised of children from a state primary school, selected by teachers on the basis of having normal motor ability. An attempt was made to match the two groups for intellectual competence by asking teachers to select children who were, in their opinion, of average or above intelligence.

Apparatus

The apparatus used in this experiment was the same as that used in Experiments 4 and 5.

Experimental Tasks

The experimental tasks were the same as those used in the location conditions of Experiments 4 and 5. Subjects were presented with standard stimulus locations which they were required to reproduce as accurately as

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3 The clumsy children were enrolled in remedial programmes conducted by The Flinders Medical Centre, The Adelaide Children's Hospital, and the Education Department of South Australia.

possible. For within-modal conditions, the standard stimulus was presented and reproduced in either the visual (V) or kinaesthetic (K) modalities. For conditions requiring translation of information between modalities, the standard stimulus was presented in the visual and reproduced in the kinaesthetic modality (VK), or presented in the kinaesthetic and reproduced in the visual modality (KV). This resulted in four experimental conditions: VVL, KKL, VKL and KVL.

Procedure

Before testing in the experimental conditions, the motor ability of the control children was assessed using the Gubbay (1989) test, and IQ was tested using the WISC-R. In other respects, the procedure followed was identical to that used in the location conditions of Experiments 4 and 5. Children who had a defect of visual acuity wore their prescribed spectacles during the experiment.

Eight children from both the clumsy and control groups were tested first in within-modal followed by translation conditions, and seven were tested in the opposite order. Within the first group, four children were tested in visual followed by kinaesthetic presentation conditions, and four were tested in the opposite order. In the second group, four children were tested first in visual followed by kinaesthetic presentation conditions, and three were tested in the opposite order.

Results

Motor Ability Scores

The same procedure as followed in Experiment 4 was used to derive composite motor ability scores, and the resulting scores are shown in

Appendix 6.1. A comparison of these scores showed that the mean motor ability of the control group (12.6, SD 1.9) was markedly superior to that of the clumsy group (7.4, SD 3.2), $t(14) = 6.32$,$p<.001$.

Intelligence Scores

Intelligence scores for both groups are shown in Appendix 6.2. A comparison of these scores showed that there was no significance difference between either the mean VIQ for the clumsy (100, SD 15) and control (105, SD 10) groups, $t(14) = 1.48, p>.05$, or the mean PIQ for the clumsy (100, SD 15) and control (108, SD 12) groups, $t(14) = 1.91, p>.05$.

Residual Error

Residual error scores are shown in Appendix 6.3. For purposes of analysis, the data were grouped into five categories of standard stimulus line length: 80-100, 105-125, 130-150, 155-175 and 180 - 200 mm. These scores were analyzed using a mixed design, 2(Group) x (2)Modality x (2)Translation x 5(Length) analysis of variance with specific effects of length analyzed as planned comparisons of trend (see Appendix 6.4).

The analysis of residual error scores revealed that there was no significant effect for either the linear ($F(1, 112) = 1.88, p>05$) or quadratic ($F(1, 112) = 1.24, p>.05$) trends of Length, and that the Group x Length interaction was not significant for either the linear ($F(1, 112) = 0.79, p>.05$) or the quadratic ($F(1, 112) = 0.51, p>.05$) trends of length. Mean residual error in translation conditions (21.7 mm) was significantly greater than that in within-modal conditions (16.9 mm), $F(1, 28) = 22.52, p<.001$, and there was a significant Length x Translation interaction for the linear trend of Length, $F(1, 112) = 6.80, p<.05$. An examination of the data revealed that error tended to increase with length in the translation, but not in the within-modal conditions. However, the effect was small.

Mean error was greater for the clumsy (22.5 mm) as compared with the control (16.1 mm) groups, $F(1, 28) = 14.11$, $p<.001$, and for presentation of the standard stimulus in the kinaesthetic (23.0 mm) as compared with the visual (15.5 mm) modality, $F(1, 28) = 58.72$, $p<.001$. Also, there was a significant Group x Translation x Modality interaction, $F(1, 28) = 4.66$, $p<.05$.

Residual error data, collapsed over length, are shown in Figure 6.1. This Figure shows that error was greater for the clumsy group, for translation conditions, and when the standard stimulus was presented in the kinaesthetic modality. Although the pattern of error was similar for both groups, Figure 6.1 shows that the significant Group x Translation x Modality interaction can be attributed to the performance of the control group in the VV condition. There was a marked difference in error between the VV and the remaining conditions in the control group which was not evident in the clumsy group.

Correlations

Pearson product moment correlations were calculated between motor ability and residual error scores for each condition. The resulting correlations are shown in Table 6.1. Higher motor ability scores were associated with lower reproduction error, resulting in negative correlations. This analysis revealed that, for all conditions, correlations were moderate to strong and statistically significant. Comparisons between correlations were made using the procedure suggested by Ferguson (1966). This revealed that there was a significant difference between correlations for the VVL and KKL conditions, $t(27) = 2.39$, $p<.05$, but there was no significant difference

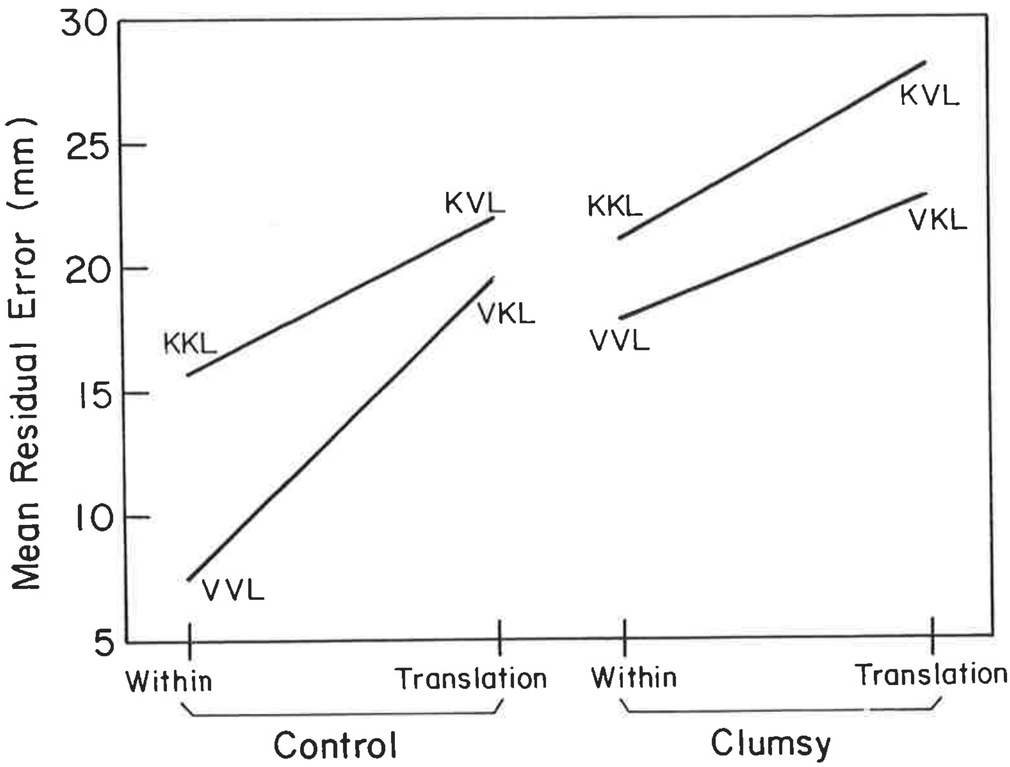


FIGURE 6.1: Residual Error collapsed over length - Experiment 6

between the correlations for the VKL and KVL conditions, $t(27) = 0.24$, $p>.05$. Further, the correlation between residual error in translation conditions and motor ability, partialling out the effects of within-modal judgement, was $r = .18$, $p>.05$.

Table 6.1

Correlations Between Motor and Residual Error Scores for All Subjects in Experiment 6

	r	*p*		*r*	*p*
VVL	-.72	<.001	Within	-.68	<.001
KKL	-.45	<.01			
VKL	-.44	<.01	Translation	-.54	<.01
KVL	-.48	<.01			

Correlations between IQ scores and motor ability were also calculated. The resulting correlations are shown in Table 6.2. This analysis revealed that for the control group correlations between motor ability and VIQ and between motor ability and PIQ were low and not significant. For the clumsy group, by comparison, whilst the correlation for VIQ was also low and not significant, that for PIQ was moderately high and significant. Further, for the combined data for both groups, the correlation between residual error in the VVL condition and motor ability, partialling out the effects of PIQ, was $r = .69$, $p<.05$.

Table 6.2

Correlations Between Motor and IQ Scores in Experiment 6

	Clumsy		**Control**	
	r	*p*	*r*	*p*
VIQ	.38	>.05	.33	>.05
PIQ	.52	<.05	.21	>.05

Discussion

The finding that residual error did not increase with length, in either within-modal or translation conditions, is similar to the error pattern observed for location strategy conditions in the Hermelin and O'Connor (1975) and Salmoni and Sullivan (1976) studies, and for residual error in Experiments 3, 4 and 5. This finding suggests that subjects in the present experiment used a location strategy in all conditions. Moreover, the absence of a Group x Strategy interaction shows that this was so for both clumsy and control children

Clumsy children were less accurate than their controls in judgements of location in the visual modality, suggesting that clumsiness is associated with a visual perceptual defect. This is consistent with the earlier findings of the Hulme et al. (1982a) experiment in which a similar experimental design was used, and of Hulme et al. (1982b) where a modification of this design was used. Moreover, the present finding is also consistent with those of Lord and Hulme (1987, 1988), who found evidence of a more general visual perceptual defect in clumsy children. Together, these findings strongly suggest an association of impaired motor ability with a visual perceptual defect. Further, the finding in this experiment of no significant between-group difference in VIQ, but a lower PIQ for the clumsy group, is also consistent with the results of the Hulme et al. (1982a) study. Since the performance subscales of the WISC-R involve visual perception, the lower than normal PIQ observed for clumsy children can be attributed to the suggested defect of visual perception. Moreover, whereas the correlations between motor ability and both VIQ and PIQ for the control children, and VIQ for the clumsy children were low and not significant, that for PIQ in the clumsy group was moderately strong and significant. Again, Hulme et al. (1982a) also found a moderately strong correlation between motor ability and PIQ. These finding suggest an association of motor and visual perceptual ability in clumsy children. The results of the present experiment, then, add support to the association of a visual perceptual defect with clumsiness suggested by Hulme et al. (1982a, 1982b) and Lord and Hulme (1987, 1988), and extend those earlier findings by showing that clumsy children have difficulty with judging locations in space in the visual modality.

In addition, the clumsy children in this experiment were less accurate than their controls in judgments of location in the kinaesthetic modality, suggesting that clumsiness is also associated with a kinaesthetic perceptual defect. Hulme et al. (1982a) similarly found that clumsy children were less accurate in judgments in the kinaesthetic modality of movement distance. Although the Smyth and Glencross (1982, 1986), Laszlo et al. (1988) and Bairstow and Laszlo (1989) studies, discussed in Chapter 2, suggest an association of clumsiness with a kinaesthetic perceptual defect, the finding of these studies were inconclusive. However, the present finding, together with the results of the Hulme et al. (1982a) experiment, suggest that clumsiness is associated with a kinaesthetic perceptual defect. In particular, the present findings show that clumsy children have difficulty with judgements of location in space in this modality.

Clumsy children were also less accurate than their controls in translation conditions, but both groups were similarly less accurate in translation, as compared with within-modal conditions. Again, this is consistent with the finding in the Hulme et al. (1982a) experiment. Lower accuracy in translation, as compared with within-modal conditions, which has also been found in other studies (e.g. Connolly & Jones, 1970; Hulme et al., 1983, 1984; Marteniuk & Rodney, 1979; Newell et al., 1979), can be attributed to the loss of accuracy resulting from the translation of information between modalities postulated by Connolly and Jones (1970). However, since in both the present and the Hulme et al. (1982a) experiments the loss of accuracy was similar for clumsy and control children, the results of neither study suggest an association of clumsiness with a specific defect of the translation process. The lower accuracy observed in translation conditions for clumsy, as compared with control children, should therefore be attributed to a loss of accuracy resulting from the suggested perceptual defect affecting judgment of the standard stimulus in both the visual and kinaesthetic modalities.

Although Hulme et al. (1982a) found a moderately strong correlation between motor ability and accuracy of judgement within the visual, but not the kinaesthetic modality, this latter finding is inconsistent with the results of the Hulme et al. (1983) experiment and of Experiment 4, and so would seem to be anomalous. On the other hand, the finding of low correlations between motor ability and reproduction accuracy in the translation conditions of the Hulme et al. (1982a) experiment can be attributed to the use of a distance strategy, together with the unsuitability of kinaesthesis for judgments of movement distance. By comparison, in the present experiment moderately strong correlations between motor ability and accuracy in judgement of location were found in all conditions. This is consistent with the findings of Experiments 4 and 5 when a location strategy was used. The present results, therefore, add support to the suggestion that judgements of location in both modalities contribute to motor ability. Therefore, since the present findings, together with those of earlier studies, show that clumsiness is associated with a perceptual defect affecting both modalities, it is reasonable to suggest that impaired motor skill in clumsy children is attributable to this perceptual defect.

As in Experiments 4 and 5, error was greater when the standard stimulus was presented in the kinaesthetic modality, but this was equally so for both groups. Again, this result can be attributed to the lack of precision in this modality, as compared with vision, that was suggested in Chapter 5. There was, however, a significant three-way interaction, and examination of the data showed that this was attributable to a between-group difference in the VVL condition, the control group being markedly more accurate than the clumsy group. Further, the correlation for the VVL condition was markedly larger than those for the other three conditions, all of which were similar in magnitude. Again, this larger correlation can be attributed to the greater accuracy of the control group in the VVL condition. The reason for this outcome is not clear, but a possible explanation is that the control children used a visual fixation strategy that enhanced their reproduction accuracy in the VVL condition. However, why the use of this strategy should be specific to the control group is not apparent.

It is clear that an alternative explanation for the outcome here, in terms of motor control rather than perception, is not supportable. As in the Hulme et al. (1982a) experiment and in Experiments 4 and 5, the observed pattern of correlations with motor ability is inconsistent with this. It is also highly improbable that the outcome of this experiment was affected by some third factor, such as the development of cognitive ability. Clumsy and control children were matched for age, and no significant difference in VIQ was found between the two groups. Moreover, the importance of perception in the performance of motor skills was discussed in Chapter 2, and it would be expected that judgements of location, in particular, play an important role. Consistent with this, the correlations observed in this experiment were in the expected direction and the pattern of correlations was as predicted.

In view of difficulties reported earlier for 8-year-olds, it is possible that, as in Experiments 4 and 5, the outcome of this experiment was affected by younger children having difficulty with understanding the requirements of the experimental tasks. On the other hand, the children in the present experiment exhibited no obvious difficulty with understanding the experimental tasks, probably because judgements of distance in the kinaesthetic modality were not involved.

In summary, then, although not conclusive, the results of this experiment are consistent with earlier findings in suggesting that abnormal clumsiness in children is associated with a perceptual defect. Moreover, the present results extend earlier findings and suggest that this defect is not modality specific, affecting ability to judge locations in space in both the visual and kinaesthetic modalities. However, as in the Hulme et al. (1982a) experiment, the present results provide no support for an association of clumsiness with a specific defect of the translation process.

CHAPTER 7
SUMMARY AND CONCLUSIONS

It was suggested in Chapter 1 that about 6% of children experience difficulties with the performance of motor skills that cannot be attributed to any identifiable disorder. Although other terms have been used, these children are commonly described as "clumsy", and their difficulties are particularly evident in the performance of activities such as games, sports, writing and drawing. The importance of impaired motor skill, however, lies in the associated and secondary emotional effects that often result. In particular, it was suggested that feelings of anxiety and depression, a poor self concept, and an expectancy of failure are likely to have a detrimental effect on learning. Consequently, some clumsy children may not achieve their full potential.

Although motor skill can be expected to be normally distributed, it was argued in Chapter 2 that this is not a satisfactory explanation of clumsiness. In some cases impaired motor skill may be attributable to normal variation, but in others there will be some cause, although this may not be apparent. An alternative is to attribute clumsiness to developmental delay, but this hypothesis does not explain the cause of the delay. Also, it is generally accepted that the age at which motor skills are acquired differs considerably, and so some children may be inappropriately classified as clumsy. Moreover, as was pointed out in Chapter 2, cases of clumsiness have been reported in young adults, and it was suggested that in about one-third of cases difficulties with the performance of motor skills persist beyond childhood.

A more likely explanation is that impaired motor skill in children can be attributed to a perceptual defect. Several studies carried out by Hulme and his colleagues, which were discussed in Chapter 2, strongly suggest that clumsiness in children is associated with a defect of visual perception. In addition, other studies suggesting the possible involvement of a perceptual defect in the kinaesthetic modality, and in the translation of information between modalities, were discussed. However, the results of these studies are inconclusive.

Research Approach

The Connolly and Jones (1970) experimental design, in which subjects are required to reproduce the length of a standard stimulus within the visual and kinaesthetic modalities, and to translate information between modalities, provides a useful technique for an investigation of perception, and of the translation process. Hulme et al. (1982a, 1983, 1984) used this design to investigate the cause of abnormal clumsiness in children and this is the most valuable approach used to date. However, it was suggested in Chapter 3 that the outcome of experiments following this design can be affected by confounding variables. It was argued that modality, the strategy used by subjects, and the suitability of modality to strategy can affect the accuracy of reproduction of the standard stimulus. Moreover, it was suggested that absolute error, which has commonly been used as a measure of performance, may not be appropriate. Experiments 1 to 3, therefore, were carried out to investigate methodological factors in experiments of this design.

The findings of Experiments 1 and 2 showed that, although subjects are instructed to reproduce the length or movement distance of a standard stimulus, they will sometimes use available information, or a strategy not consistent with those instructions, to facilitate their task. In particular, while subjects may comply with the experimenter's instructions and reproduce the length or movement distance of the standard stimulus (a "distance" strategy), they may alternatively reproduce the location of the end-point of the standard stimulus line or movement distance (a "location" strategy). Moreover, as was discussed in Chapter 3, Hermelin and O'Connor (1975) and Salmoni and Sullivan (1976) have demonstrated that distance and location strategies are associated with different error patterns. An interpretation of the results of Experiment 2 on the basis of these earlier findings showed that, when the standard stimulus was presented in the visual modality, subjects tended to follow the experimenter's instructions and so use a distance strategy; whereas when the standard stimulus was presented in the kinaesthetic modality they tended to use a location strategy.

Differences between conditions in the patterns of algebraic error were observed in both experiments, and it was concluded that algebraic error was affected by contextual factors. In particular, it was argued that, when a distance strategy is used, algebraic error will be affected by contextual effects, resulting in an overestimation or underestimation of length, whereas when a location strategy is used a similar effect will not be present. Contextual effects can be expected to differ between experiments and conditions within an experiment. Moreover, these effects are difficult, if not impossible, to determine. Since absolute error is a function of algebraic and variable error (Schutz & Roy, 1973), absolute error will also be affected by unknown contextual effects. Interpretation of the results of

Experiments 1 and 2, and subsequent experiments, therefore, was based on residual error, which provides a measure of performance that excludes contextual bias.

In Experiment 3 subjects were required to reproduce either the length or the location of a standard stimulus in tasks requiring the translation of information between modalities. The resulting patterns of error were those predicted for distance and location strategies and similar to those observed by Hermelin and O'Connor (1975) and Salmoni and Sullivan (1976) for their distance and location strategies respectively.

It was argued in Chapter 3 that vision is suitable for judgements of both location and distance, and that kinaesthesis is suitable for judgements of location, but not distance. Therefore, it was suggested that the asymmetry in performance between translation tasks observed by a number of investigators can be attributed to differences in the suitability of modality to strategy. In particular, it was argued that in translation tasks, because kinaesthesis is not suitable for judgements of distance, when a distance strategy is used a loss of accuracy will result, whereas since both modalities are suitable for judgements of location, when a location strategy is used there will be no comparable loss. Consistent with this reasoning, in Experiment 3 greater error was found for translation tasks when a distance strategy was used, regardless of the direction of translation between modalities, i.e. kinaesthesis to vision, or vision to kinaesthesis. On the basis of these results it was suggested that the inconsistent findings of asymmetry between translation tasks in earlier studies discussed in Chapter 3 could be attributable to differences in strategies used by subjects. Moreover, greater error was found when the standard stimulus was presented in the kinaesthetic, as compared with the visual modality, and this was attributed to a lack in precision of information in kinaesthesis, as compared with vision.

Manipulation of vision of the surround in Experiments 1 and 2 had no significant effect on reproduction accuracy. The use of visual cues in the surround could facilitate reproduction when a location strategy was used. Furthermore, a visual frame of reference could also be used as an aid to judging the length of standard stimuli, and following Experiment 2 one subject reported that he had used the monitor screen as a visual frame of reference, judging the length of the stimulus line in relation to the width of the screen. It was suggested in Chapter 4 that other subjects may also have used this strategy, thereby accounting for the absence of an effect of vision in Experiments 1 and 2.

In summary, the findings of Experiments 1 to 3 show that modality, strategy, and suitability of modality to strategy can be confounding variables in experiments of this design, and that absolute error is not an appropriate measure of performance. Further, although no significant effect of manipulation of vision of the surround was found, it is likely that the use of a visual frame of reference can also affect the outcome of experiments of this type. Although vision of the surround can be precluded by testing in complete darkness, it was argued in Chapter 4 that such an approach is unsuitable when the subjects are children. It was concluded that it is difficult to design an experiment of this type in which all possible confounding variables are excluded; but that strategy can be controlled; contextual effects can be excluded by the use of residual error as a measure of performance; and the use of visual cues in the surround can be precluded or minimized by screening.

Perceptual, Translation and Motor Abilities

Experiments 1 to 3 investigated only translation tasks and the subjects were adults. Experiments 4 and 5 were therefore carried out to investigate the effects of the same experimental design factors with children as subjects, using both within-modal and translation tasks, but because of the problems associated with testing children in complete darkness, vision of the surround was not manipulated. In addition, these experiments were designed to investigate the development of perceptual and translation abilities, and the relationship between these abilities and motor skill.

In Experiments 4 and 5 the children tested were aged 8, 10 and 12 years old, giving an age range of four years. However, it became evident that the 8-year-old children had difficulty with understanding the requirements of the experimental tasks when judgements of distance in the kinaesthetic modality were required. Moreover, analyses of the data revealed that these children had not used distance and location strategies as instructed. Consequently, data for the 8-year-old children were excluded from the final analyses.

For within-modal tasks in Experiment 4, error was greater both when a distance, as compared with a location strategy, was used, and in the kinaesthetic as compared with the visual modality. These findings were consistent with those of Experiment 3. By comparison, although error was also greater for the translation tasks in Experiment 5 when a distance strategy was used and when the standard stimulus was presented in the kinaesthetic modality, these differences were not statistically significant. An explanation for this disparity between experiments was developed in terms of a slower development of translation ability than of within-modal perceptual ability, which would be consistent with the earlier findings of

Jackson (1973), together with the small age difference between groups in Experiment 5.

Reproduction accuracy for judgements of location in the within-modal tasks of Experiment 4 improved with age in both the visual and kinaesthetic modalities. These findings, which are similar to those of Connolly and Jones (1970) and Hulme et al. (1983), were consistent with the development of perceptual ability during childhood discussed in Chapter 2. On the other hand, no improvement in accuracy with age was found for judgements of distance in the visual modality. This finding was, however, regarded as anomalous and may have been the consequence of the small between-group age difference. Further, although it was argued that kinaesthesis is not suitable for judgements of distance and that this would be expected to be so at all ages, an improvement with age was found for accuracy of judgements of distance in the kinaesthetic modality. However, it was suggested that this may have resulted from subjects having based judgements of distance in the kinaesthetic modality on the location of the start and end-points of the standard stimulus and reproduction lines. Although resulting in error because of the offset between start-points for presentation and reproduction, this strategy could have been used. Moreover, since kinaesthesis is suitable for judgements of location, this could account for the observed improvement with age for conditions requiring judgements of distance in the kinaesthetic modality.

No significant difference in reproduction accuracy was found between the 10 and 12-year-old groups for the translation tasks of Experiment 5, and there was no significant Modality x Strategy interaction. Nonetheless, whilst there was little between-group difference in accuracy of judgements of location, error in judgements of distance was greater for the

10-year-old children. This pattern is consistent with both modalities being suitable for judgements of location, but kinaesthesis being unsuitable for judgements of movement distance at all ages. Again, the absence of significant effects in these analyses was attributed to the small between-group age difference.

The results of Experiments 4 and 5 also showed that relationships observed between motor and both perceptual and translation abilities can be affected by strategy and modality. In Experiment 4 significant correlations were found between motor ability and accuracy in judgements of both distance and location in the visual modality, and of location in the kinaesthetic modality. These correlations were consistent with the suggested suitability of modality to strategy, and showed that ability to make such judgements contributes to motor skill. On the other hand, the finding of a moderately strong correlation between accuracy of judgements of distance in the kinaesthetic modality and motor ability was inconsistent with the argued unsuitability of kinaesthesis for such judgements. However, it has already been suggested that subjects may have based judgements of distance in the kinaesthetic modality on judgements of the locations of the start and end-points of movements. Since kinaesthesis is suitable for judgements of location, this could account for the finding of a moderately strong correlation for judgements of movement distance in the kinaesthetic modality.

Moderately strong correlations between accuracy in translation tasks and motor ability were found in Experiment 5 for translation of location information both from vision to kinaesthesis and from kinaesthesis to vision, and this was attributed to both modalities being suitable for judgements of location. By comparison, only low correlations between reproduction accuracy and motor ability were found for translation tasks when a distance strategy was used. Whilst it has been suggested that within the kinaesthetic modality judgements of standard stimulus and reproduction movements could be similarly based on judgements of location, when a translation of distance information between modalities is required this strategy would be difficult, if not impossible to use. Consequently, in translation tasks judgements of either the standard stimulus or reproduction movement distance in the kinaesthetic modality must be made. Therefore, the low correlations found when a distance strategy was used in translation tasks were attributed to the unsuitability of kinaesthesis for judgements of movement distance.

Consistent with the argument advanced in Chapter 2, then, the findings of Experiments 4 and 5 showed that both perceptual ability and the ability to translate information between modalities contribute to motor skill. The finding of a moderately strong correlation between accuracy of judgements of distance in the kinaesthetic modality and motor ability in Experiment 4 may be attributable to subjects basing judgements of movement distance on the location of the start and end points of movements. With the exception of this anomalous finding, the patterns of correlations observed were consistent with the suitability of modality to strategy discussed in Chapter 3. In particular, the findings showed that judgements of location in both modalities and of distance in the visual, but not the kinaesthetic modality, contribute to motor ability.

Although the outcome of Experiments 4 and 5 was affected by the small age range of the subjects included in the final analyses, the effects of modality, strategy and suitability of modality to strategy were clearly evident in the within-modal tasks of Experiment 4; suitability of modality to strategy in translation tasks was also evident in Experiment 3. Therefore, it was decided not to replicate Experiments 4 and 5 using a larger age range. Also, although the suggestion that translation ability develops more slowly than does within-modal perception is equivocal and warrants further investigation, it was decided that this did not restrict an investigation of the possible contribution of a defect in this ability to impaired motor skill in children. This issue was therefore not pursued.

Impaired Motor Skill

Since the results of the Hulme et al. (1982a, 1982b) studies showed a clear association between clumsiness and defective ability to judge length in the visual modality, it was decided not to investigate this ability. Although a moderately strong correlation between accuracy in judgements of movement distance in the kinaesthetic modality and motor ability was found in Experiment 4, it has been suggested that this may have resulted from subjects basing judgements of movement distance on the locations of the start and end-points of movements. By comparison, consistent with the suggestion that kinaesthesis is not suitable for judgements of distance, and hence would contribute little to motor skill, when a distance strategy was used for translation tasks in Experiment 5 low correlations between reproduction accuracy and motor ability were found. Finally, it became evident in Experiment 4 that the 8-year-old children had difficulty with understanding the distinction between reproducing location and distance in the kinaesthetic modality. Therefore, it was decided not to investigate a possible contribution to impaired motor skill of a defect in the ability to judge movement distance in the kinaesthetic modality.

On the other hand, in Experiment 4 significant correlations were found between accuracy in judgements of location in both vision and kinaesthesis, and in Experiment 5 between accuracy in translation tasks and motor ability when a location strategy was used. These findings were consistent with the suggestion that both vision and kinaesthesis are suitable for judgements of location, and that the ability to make judgements of location and to translate location information between modalities should contribute to motor skill. A defect in the ability to make such judgements, or to translate location information between modalities, therefore, would be expected to result in impaired motor skill.

Experiment 6 was designed to investigate the possible contribution to impaired motor skill of a defect in the ability to judge locations in space, in both the visual and kinaesthetic modalities; and of a defect in the ability to translate location information between modalities. The perceptual and translation abilities of a sample of children, whose motor ability was markedly below normal, were compared with those of matched controls. As in Experiments 4 and 5, significant correlations were found between motor ability and accuracy of judgements of location in both the visual and kinaesthetic modalities, and in the translation of location information between modalities, adding support to the argument that both perceptual and translation abilities contribute to motor skill.

Motor impaired children were less accurate in judgements of location, in both modalities, than were their controls, suggesting an association of impaired motor skill with perceptual defects in both the visual and kinaesthetic modalities. Further, motor impaired children were also less accurate than their controls in the translation of location information between modalities. Both groups, however, were less accurate in translation than in within-modal tasks, and this was attributed to the loss of information resulting from the translation of information suggested by

Connolly and Jones (1970). Moreover, both groups were similarly affected by this loss of information. Thus, the findings of Experiment 6 provided no support for an association of impaired motor skill with a specific defect in the translation process.

Conclusions

Earlier studies, which were discussed in Chapter 2, suggest an association of impaired motor skill with a visual perceptual defect. The finding in Experiment 6 of a similar association is consistent with these earlier studies, and extends them by showing that the perceptual defect affects ability to judge locations in space. Some studies discussed in Chapter 2 suggest that a perceptual defect in the kinaesthetic modality may also be involved in impaired motor skill, but the results of these studies are inconclusive. The finding in Experiment 6 of an association of impaired motor skill with a perceptual defect in the kinaesthetic modality, therefore, adds weight to these earlier suggestions. Although some earlier findings have suggested that a defect in the translation of information between modalities may also contribute to impaired motor skill, the results of Experiment 6 provided no support for this suggestion.

In summary, the results of Experiment 6 suggest that impaired motor skill in children is associated with a perceptual defect that affects ability to judge locations in space, in both the visual and kinaesthetic modalities. The cause of such a defect is beyond the scope of this study. One possibility is that a perceptual defect is the consequence of minimal brain damage but, as was pointed out in Chapter 2, this concept is problematic, and in many motor impaired children there is no evidence to suggest brain injury. Another possible explanation is that, due to normal variation, perceptual ability is below normal. In the Connolly and Jones (1970) and Hulme et al.

(1983) studies and in Experiment 4, accuracy of perceptual judgements was found to improve with age. Therefore, as a result of normal variation, it is possible that in some children perceptual development may be slower than in others. This could, in part, account for the generally accepted variation in age at which motor milestones are reached during childhood. Further, again due to normal variation, it is possible that in some individuals perceptual abilities remain permanently lower than normal. Impaired motor skill could, then, be attributable to a perceptual defect which is either transitory or permanent. This would explain the finding in the Knuckey and Gubbay (1983) study that, eight years following their identification as clumsy, less severely affected children had improved to a normal level of performance, whereas those who were more severely affected still experienced difficulties with motor skills.

Correlational evidence, of course, cannot establish causality. Although the conclusions reached here are based on sound theoretical reasoning, and are intuitively appealing, it is possible that some other factor affects both perceptual and motor ability. For example, it could be argued that both are determined by the development of general intellectual ability. Since in a number of studies discussed in Chapter 2, and in Experiment 6, no difference in verbal intelligence was found between clumsy children and their controls, this is unlikely. One approach to this problem would be a longitudinal study, but experiential factors and differences in rates of development are likely problems. An alternative is a training study, such as used by Laszlo et al. (1988). Again, however, as discussed in Chapter 2, there can be problems with this approach.

Future Research

The findings of Experiment 6, together with those of earlier studies discussed in Chapter 2, suggest that impaired motor skill in otherwise normal children is associated with a perceptual defect which is not modality specific. This defect, therefore, can be investigated in either the visual or kinaesthetic modality. As was discussed in Chapter 2, vision is the predominant modality, and Adams et al. (1977) have demonstrated that vision is the more powerful modality in motor learning. Moreover, in Experiments 4 and 5, 8-year-old children were found to have difficulty with judgements in the kinaesthetic modality, suggesting that kinaesthetic perception has not fully developed at this age. Future investigation of the contribution of a perceptual defect to impaired motor skill in children, therefore, could appropriately be restricted to the visual modality.

Movement control is the basis of motor skill, and the ability to use visual feedback for movement control can be readily investigated. Lord and Hulme (1988), for example, investigated the ability of clumsy children to control movement using a rotary pursuit tracking task. Such a task requires subjects to superimpose an index, or pointer, on a moving target. Tracking accuracy, therefore, would be expected to be determined primarily by ability to judge location. However, ability to judge distance, e.g. from the index or pointer to the target, could also be involved. The findings of Experiment 6 suggest that impaired motor skill is associated with a defect in the ability to judge location, and those of Hulme et al. (1982a, 1982b) suggest that a defect in the ability to judge distance in the visual modality is also involved. Consequently, children who have impaired motor ability would be expected to perform poorly in a tracking task.

Lord and Hulme (1988) found that the clumsy children in their experiment performed more poorly than did controls, and they suggest that the performance of the clumsy children was limited by impaired visual feedback. However, in this experiment subjects were required to hold a stylus on the moving target and, although this would have imposed only limited demands, it is possible that difficulty in movement control could have affected the clumsy children's performance. By comparison, in Experiment 6 subjects controlled the movement of the spot of light on the screen by simply holding a joy-stick to the left or right, and the results suggested that motor control did not affect the outcome. Therefore, a tracking task, in which subjects control the index or pointer by similar use of a joy-stick, would impose maximum demands on the use of visual feedback with minimal demands on motor control.

A pursuit tracking task should therefore provide a useful means for investigating the contribution of a visual perceptual defect to impaired motor skill. An additional advantage of such a task is that, since the target moves, subjects would be unable to use a visual fixation strategy, which it has been suggested, some subjects may have used in Experiment 6. Moreover, a particular advantage of using a visual tracking task is that visual perception can be disrupted. As was discussed in Chapter 2, Smith (1962) demonstrated that displaced or delayed visual feedback impaired performance in drawing, and Held (1965) showed that displacement of the visual field was detrimental to reaching and pointing movements. Although subjects can be expected to adjust to visual displacement, Smith (1962) found little or no adaptation to delayed feedback. Therefore, if in a visual tracking task a delay is introduced between operation of the controlling device (e.g. a joy-stick) and movement of the pointer or index, performance can be expected to be detrimentally affected.

If impaired motor skill is attributable to a perceptual defect, sufficient disruption of visual feedback should result in the performance of a control group falling to the level of that of a group of motor impaired children. Moreover, the degree of disruption required to reduce performance to this level would give an indication of the extent of the defect in the motor impaired group. The effect of a similar disruption on the performance of motor impaired children, however, is difficult to predict. If impaired motor skill is attributable to a perceptual defect which is severe, then it may be that disruption to visual feedback will have little effect, in the same way that precluding visual cues would have no effect on the performance of a blind person. Further, it is possible that children who have impaired motor skill may have already developed strategies for movement control, which to some extent counter any perceptual defect. Again, therefore, disruption of feedback may have a limited effect on the performance of these children. The most likely outcome, however, is that some degree of distortion of feedback will result in the performance of motor impaired children being at chance level, and that the same degree of distortion will impair the performance of control subjects, but not reduce their performance to a chance level.

An interesting possibility is that impaired motor skill is associated with a slower than normal rate of processing of information. Smyth and Glencross (1986) found that the kinaesthetic reaction time of clumsy children was longer than that of controls, but that there was no between group difference in visual reaction time. On the basis of these findings they suggested that clumsy children suffer from a slower than normal rate of processing of information which is specific to the kinaesthetic modality. However, it is not clear why such a defect should be so specific. It is possible that a perceptual defect could result in a slow rate of processing, and the present findings suggest that impaired motor skill is associated with a perceptual defect which is not modality specific. Therefore, it is possible that impaired motor skill is associated with a slow rate of processing that is similarly not modality specific, but that the Smyth and Glencross (1986) experiment was not sensitive enough to reveal this. If so, the delay in feedback required to reduce the performance of a control group in a tracking task to that of motor impaired children would give an indication of the processing delay associated with impaired motor skill.

Summary

The experiments reported here have concentrated on the Connolly and Jones (1970) experimental design and the application of this design to the study of impaired motor skill in children. The results show that there are problems associated with this design that are difficult to overcome. In particular, it is apparent that strategy, modality, suitability of modality to strategy, and contextual effects can be confounding variables. Also, it has been shown that, in experiments of this type, absolute error is not an appropriate measure of performance, but that residual error, which provides a measure of accuracy after excluding contextual effects, is the preferred alternative. Finally, an alternative explanation to that proposed by Connolly and Jones has been developed for asymmetry between translation conditions.

Nonetheless, using a modification of this design, Experiment 6 has extended earlier findings, suggesting that impaired motor skill in otherwise normal children is associated with a perceptual defect which is not modality specific. As has been pointed out, however, such an association alone is not evidence of causality, and it has been proposed that the use of a tracking task, together with disruption of feedback, would be a valuable approach for future investigation of the contribution of a perceptual defect to impaired motor skill in children.

Appendix 4.1

Description of Apparatus

There were four major items of equipment; a monochrome video monitor, a handle mounted on a track, a joy-stick and a personal computer (PC).

Video Monitor

A monochrome video monitor with a 40cm wide screen was used for presentation and reproduction of line lengths in the visual modality. To prevent reflections on the screen, it was covered with black voile material.

Handle and Track

The handle used for presentation and reproduction of movement distances was mounted on a 30cm wide track. Movement of the handle was smooth and with a low level of friction. The track was constructed by mounting two parallel steel bars in a heavy metal frame. On each end of the track a sheave was mounted and a matching timing belt, which was fixed to the handle, was positioned on the sheaves so that movment of the handle rotated them. A Borg Warner miniature electro-magnetic clutch was coupled to the left sheave.

Clutch Operation

When the clutch was engaged the handle could not be moved. The clutch was disengaged to allow movement for presentation and reproduction of standard stimulus and movement distances. When the handle reached its terminal location during presentation of the standard stimulus, and when it was returned to the start point, the clutch was engaged to stop movement.

Position Transducer

A position transducer was coupled to the left sheave so that the position of the handle could be determined. This consisted of a ten-turn potentiometer, the output of which was fed to an eight-bit analogue to digital (A/D) converter. The A/D converter output was read by the PC. Due to the eight bit resolution of the A/D converter, the location of the handle could be quantified into 256 discrete positions on the track.

Joy-stick

The joy-stick used for reproduction of lines in the visual modality operated in a digital manner. Holding it to the right resulted in a line being drawn from left to right with a velocity of 30mm/s; holding it to the left reduced the line length with the same velocity.

Accuracy

A possible source of inaccuracy arose from the mechanical components of the apparatus. When movement was stopped by the clutch a small overshoot of the terminal position was possible. A further potential source of error arose from the A/D converter's accuracy of $\pm$ 1 least significant bit in any conversion. Therefore, because of the possible number of discrete positions on the track (256), over the length of lines involved in the experiment the location of the end point could be measured with an accuracy of approximately $\pm$ 1mm.

To confirm this expected precision, the accuracy of the apparatus was measured empirically. A ruler was fixed along the track and a pointer was attached to the handle, so that its movement could be measured, and the ends of the line lengths used were marked on the monitor screen. For both cross-modal conditions, i.e. VK and KV, a full set of 72 trials was conducted. Care was taken to reproduce the stimulus length accuratey, using the ruler and the markings on the monitor screen.

The mean error for drawing line lengths in the visual modality was 1.04mm. However, when lines were drawn in this modality it was difficult to avoid a small error. This arose because the line was drawn on the phosphorus coating of the screen, i.e. on the inside of the cathode ray tube, whilst markings were on the outside. Because of the thickness of the glass it was difficult to avoid a small error. The mean error measured in the visual modality is therefore subject to this limitation. For reproduction of lines in the kinaesthetic modality, the mean error was 0.22mm. Therefore, the findings of this empirical test show that the error of measurement in the apparatus was no greater than approximately $\pm$ 1mm.

Appendix 4.2
Error Scores
Experiment 1
Mean Absolute Error (mm)

Line Length	Condition VKA	VKP	KVA	KVP
25	9.5	9.8	15.1	13.9
50	18.5	15.5	20.5	17.1
75	25.0	21.9	27.4	25.3
100	34.4	29.9	25.4	23.5
125	39.3	37.9	28.9	24.5
150	45.5	42.9	32.6	31.2
Mean	28.7	26.3	25.0	22.6

Mean Algebraic Error (mm)

Line Length	Condition VKA	VKP	KVA	KVP
25	- 2.3	- 0.2	12.9	12.7
50	-10.0	- 7.2	15.6	12.7
75	-18.8	-15.4	19.0	18.6
100	-31.3	-28.9	18.1	16.3
125	-38.0	-36.7	18.4	17.8
150	-42.9	-40.9	19.6	19.3
Mean	-23.9	-21.5	17.3	16.2

Mean Residual Error (mm)

Line Length	Condition VKA	VKP	KVA	KVP
25	6.2	6.1	8.6	10.4
50	8.4	7.3	9.2	9.2
75	10.1	10.4	13.3	14.3
100	10.3	9.7	14.9	14.0
125	11.0	10.5	14.8	16.4
150	14.3	12.1	19.9	19.2
Mean	10.0	9.4	13.5	13.9

Appendix 4.3
Absolute Error Analysis of Variance
Experiment 1

Source	DF	SS	MS	F	P
Subject	11	14344.13	1304.01		
Length (L)	5	21861.66	4372.33	41.13	<.001
Linear	1	21648.13	21648.13	203.63	<.001
Quadratic	1	92.96	92.96	0.87	
Deviations	3	120.58	40.19	0.38	
Residual	55	5847.22	106.31		
Vision (V)	1	413.71	413.71	1.01	
Residual	11	4491.65	408.33		
Condition (C)	1	999.57	999.57	0.70	
Residual	11	15727.21	1429.75		
L x V	5	66.25	13.25	0.30	
Linear	1	8.94	8.94	0.20	
Quadratic	1	42.34	42.34	0.95	
Deviations	3	14.97	4.99	0.11	
Residual	55	2459.57	44.72		
L x C	5	3652.66	730.59	6.74	<.001
Linear	1	3244.37	3244.37	23.92	<.001
Quadratic	1	9.94	9.94	0.09	
Deviations	3	398.35	132.78	1.22	
Residual	55	5964.91	108.45		
V x C	1	0.00	0.00	0.00	
Residual	11	2940.29	267.30		
L x V x C	5	64.13	12.83	0.44	
Linear	1	2.25	2.25	0.08	
Quadratic	1	5.54	5.54	0.19	
Deviations	3	56.33	18.78	0.65	
Residual	55	1588.69	28.89		
Total	287				

Appendix 4.4
Algebraic Error Analysis of Variance
Experiment 1

Source	**DF**	**SS**	**MS**	**F**	**P**
Subject	11	28255.64	2568.69		
Length (L)	5	11932.76	2386.55	21.13	<.001
Linear	1	11506.59	11506.59	101.86	<.001
Quadratic	1	2.88	2.88	0.03	
Deviations	3	423.29	141.10	1.25	
Residual	55	6212.79	112.96		
Vision (V)	1	29.57	29.57	0.07	
Residual	11	4624.35	420.40		
Condition (C)	1	112181.24	112181.24	27.52	<.001
Residual	11	44836.69	4076.06		
L x V	5	18.39	3.68	0.08	
Linear	1	0.09	0.09	0.00	
Quadratic	1	0.24	0.24	0.01	
Deviations	3	18.05	6.02	0.14	
Residual	55	2417.75	43.96		
L x C	5	20823.75	4164.75	45.66	<.001
Linear	1	20539.21	20539.21	225.18	<.001
Quadratic	1	162.77	162.77	1.78	
Deviations	3	121.78	40.59	0.45	
Residual	55	5016.58	91.21		
V x C	1	209.60	209.60	0.34	
Residual	11	6743.64	613.06		
L x V x C	5	34.61	6.92	0.14	
Linear	1	5.45	5.45	0.11	
Quadratic	1	10.52	10.52	0.21	
Deviations	3	18.64	6.21	0.12	
Residual	55	2743.97	49.89		
Grand Total	287	246081.33			

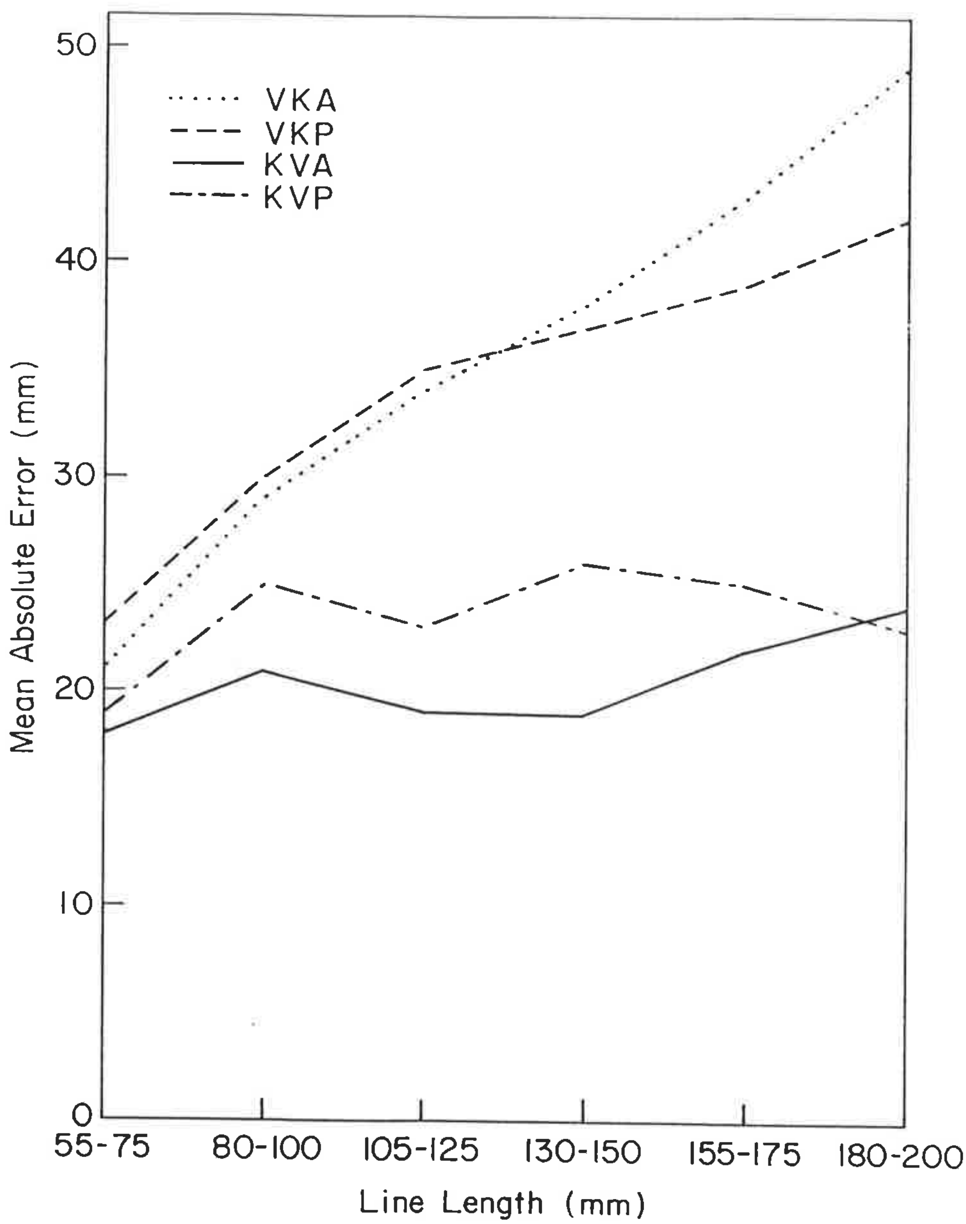
Appendix 4.5
Residual Error Analysis of Variance
Experiment 1

Source	DF	S	MS	F	P
Subject	11	1253.16	113.92		
Length (L)	5	2389.81	477.96	30.73	<.001
Linear	1	2228.99	2228.99	143.32	<.001
Quadratic	1	3.13	3.13	0.20	
Deviations	3	157.69	52.56	3.38	<.05
Residual	55	855.41	15.55		
Vision (V)	1	1.11	1.11	0.06	
Residual	11	200.31	18.21		
Condition (C)	1	1144.09	1144.09	8.37	<.05
Residual	11	1503.43	136.68		
L x V	5	51.91	10.38	1.02	
Linear	1	14.97	14.97	1.48	
Quadratic	1	1.26	1.26	0.12	
Deviations	3	35.94	11.98	0.56	
Residual	55	557.61	10.14		
L x C	5	168.78	33.76	1.59	
Linear	1	117.83	117.83	5.54	<.05
Quadratic	1	15.02	15.02	0.71	
Deviations	3	35.94	11.98	0.56	
Residual	55	1170.71	21.29		
V x C	1	22.45	22.45	0.76	
Residual	11	326.67	29.70		
L x V x C	5	11.47	2.29	0.17	
Linear	1	0.01	0.01	0.00	
Quadratic	1	4.90	4.90	0.37	
Deviations	3	6.56	2.19	0.16	
Residual	55	736.37	13.39		
Total	287	10393.29			

Appendix 4.6

Absolute Error

Experiment 2



Mean Absolute Error (mm)

Appendix 4.6 (Continued)

Mean Absolute Error (mm)

Experiment 2

Length	VKA	VKP	KVA	KVP
55- 75	20.5	22.8	18.4	19.2
80-100	28.9	29.7	21.2	24.8
105-125	34.3	34.7	18.6	23.5
130-150	37.8	37.2	18.8	25.9
155-175	43.4	39.3	22.1	24.9
180-200	49.1	42.5	24.1	23.1
Mean	35.7	34.4	20.5	23.6

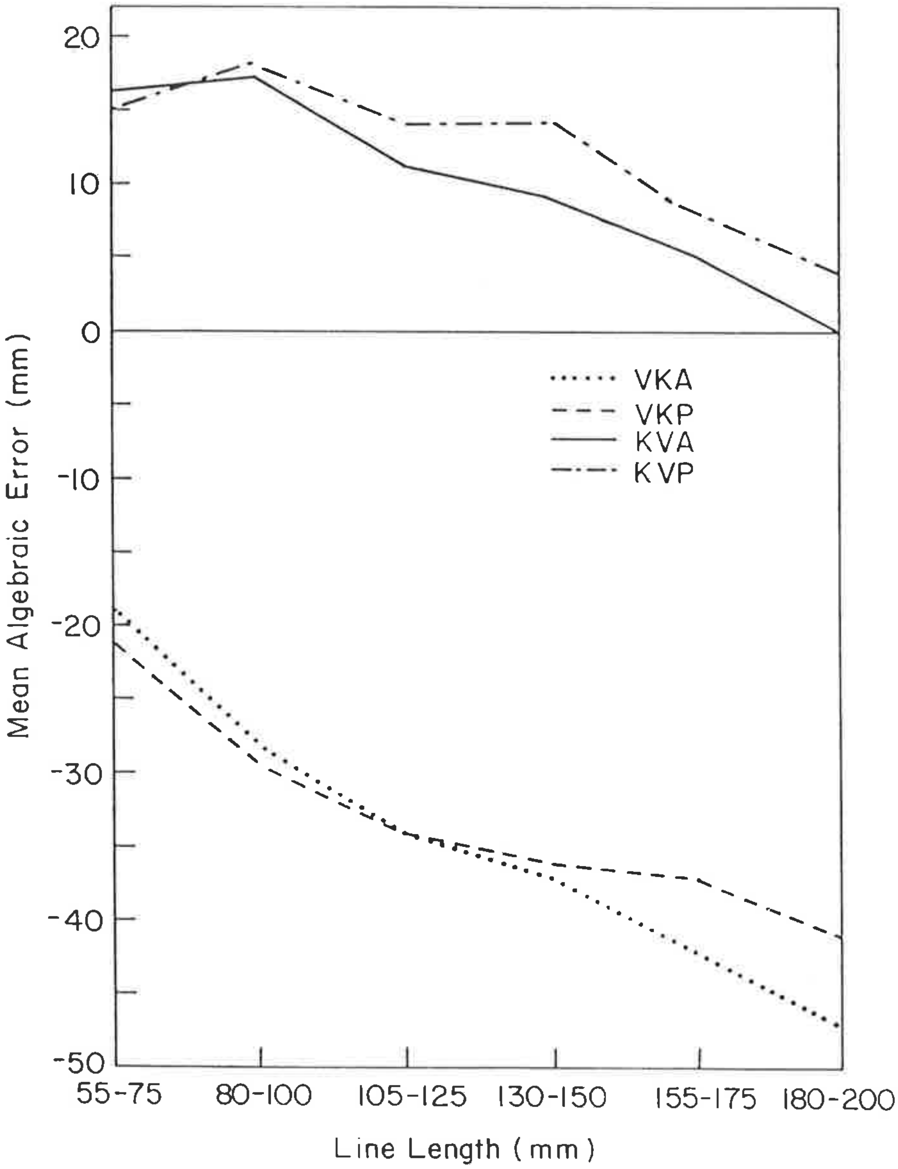
Appendix 4.6 (Continued)
Absolute Error Analysis of Variance
Experiment 2

Source	DF	SS	MS	F	P
Subject	11	23458.33	2132.58		
Length (L)	5	6248.73	1249.75	13.29	<.01
Linear	1	5965.07	5965.07	63.41	<.01
Quadratic	1	127.11	127.11	1.35	
Deviations	3	156.55	52.18	0.56	
Residual	55	5174.13	94.0		
Vision (V)	1	53.99	53.99	0.04	
Residual	11	14478.56	1316.23		
Condition (C)	1	12143.31	12143.31	41.87	<.01
Residual	11	3189.98	290.00		
L x V	5	420.53	84.11	4.16	<.01
Linear	1	206.76	206.76	10.23	<.01
Quadratic	1	187.16	187.16	9.26	<.01
Deviations	3	26.61	8.87	0.44	
Residual	55	1111.17	20.28		
L x C	5	3114.87	622.97	8.91	<.01
Linear	1	3022.34	3022.34	43.23	<.01
Quadratic	1	24.31	24.31	0.35	
Deviations	3	68.22	22.74	0.33	
Residual	55	3845.62	69.92		
V x C	1	336.92	336.92	0.69	
Residual	11	5362.59	487.51		
L x V x C	5	169.75	33.95	0.56	
Linear	1	113.56	113.56	1.88	
Quadratic	1	51.32	51.32	0.85	
Deviations	3	4.87	1.62	0.03	
Residual	55	3325.72	60.47		
Total	287	82434.20			

Appendix 4.7

Albebraic Error

Experiment 2



Mean Algebraic Error (mm)

Appendix 4.7 (Continued)

Mean Algebraic Error (mm)

Experiment 2

Length	**VKA**	**VKP**	**KVA**	**KVP**
55-75	-19.4	-20.9	15.5	15.1
80-100	-28.1	-28.5	16.5	18.1
105-125	-34.0	-33.8	10.9	13.9
130-150	-37.0	-35.8	8.8	14.3
155-175	-41.7	-37.4	5.5	7.6
180-200	-47.5	-41.0	0.2	4.1
Mean	-34.6		9.6	12.2

Appendix 4.7 (Continued)
Algebraic Error Analysis of Variance
Experiment 2

Source	DF	SS	MS	F	P
Subject	11	15958.39	1450.76		
Length (L)	5	11332.41	2266.48	16.24	<.01
Linear	1	11206.60	11206.60	80.28	<.01
Quadratic	1	3.58	3.58	0.03	
Deviations	3	122.23	40.74	0.29	
Residual	55	7677.81	139.68		
Vision (V)	1	338.65	338.65	0.63	
Residual	11	5910.36	537.31		
Condition (C)	1	143447.06	143447.06	35.90	<.01
Residual	11	43949.79	3995.44		
L x V	5	291.37	58.27	1.97	
Linear	1	279.40	279.40	9.43	<.01
Quadratic	1	0.00	0.00	0.00	
Deviations	3	11.97	3.99	0.14	
Residual	55	1630.21	29.64		
L x C	5	1254.97	250.99	2.25	
Linear	1	572.80	572.80	5.14	<.05
Quadratic	1	506.81	506.81	4.55	<.05
Deviations	3	175.36	58.45	0.53	
Residual	55	6126.43	111.39		
V x C	1	15.26	15.26	0.01	
Residual	11	27511.58	2501.05		
L x V x C	5	114.14	22.83	0.39	
Linear	1	35.53	35.53	0.61	
Quadratic	1	45.58	45.58	0.78	
Deviations	3	33.03	11.01	0.19	
Residual	55	3230.50	58.74		
Total	287	268788.91			

Appendix 4.8

Mean Residual Error (mm)

Experiment 2

Length	VKA	VKP	KVA	KVP
55- 75	7.6	6.4	11.5	9.6
80-100	10.0	9.1	11.7	10.3
105-125	9.1	10.3	11.0	10.9
130-150	10.7	9.9	11.5	10.8
155-175	11.7	10.9	11.4	12.2
180-200	11.6	12.1	12.3	11.6
Mean	10.1	9.8	11.6	10.9

Appendix 4.9
Residual Error Analysis of Variance
Experiment 2

Source	DF	SS	MS	F	P
Subject	11	790.05	71.82		
Length (L)	5	291.77	58.36	6.20	
Linear	1	269.08	269.08	28.60	<.01
Quadratic	1	4.13	4.13	0.44	
Deviations	3	18.57	6.19	0.66	
Residual	55	517.51	9.41		
Vision (V)	1	16.38	16.38	0.97	
Residual	11	185.42	16.86		
Condition (C)	1	117.45	117.45	4.54	
Residual	11	284.31	25.85		
L x V	5	37.14	7.43	0.94	
Linear	1	15.13	15.13	1.91	
Quadratic	1	6.20	6.20	0.78	
Deviations	3	15.82	5.27	0.67	
Residual	55	435.56	7.92		
L x C	5	86.83	17.37	2.02	
Linear	1	70.52	70.52	8.22	<.01
Quadratic	1	9.14	9.14	1.06	
Deviations	3	7.18	2.39	0.28	
Residuai	55	472.11	8.58		
V x C	1	1.94	1.94	0.05	
Residual	11	426.71	38.79		
L x V x C	5	16.03	3.21	0.37	
Linear	1	1.30	1.30	0.15	
Quadratic	1	1.37	1.37	0.16	
Deviations	3	13.36	4.45	0.51	
Residual	55	401.30	8.75		
Total	287	4160.52			

Appendix 4.10

Mean Residual Error (mm)

Experiment 3

Line Length	Condition KVD	VKD	KVL	VKL
55- 75	11.9	8.4	8.9	7.3
80-100	12.4	10.3	11.4	7.4
105-125	12.0	11.8	9.9	8.2
130-150	15.3	13.0	11.9	8.8
155-175	17.6	14.0	12.3	9.9
180-200	19.4	16.6	15.3	10.1
Mean	14.8	12.4	11.6	8.6

Appendix 4.11
Residual Error Analysis of Variance
Experiment 3

Source	DF	SS	MS	F	P
Subject	11	976.20	88.75		
Length (L)	5	1270.92	254.18	24.51	<.01
Linear	1	1219.47	1219.47	117.58	<.01
Quadratic	1	32.50	32.50	3.13	
Deviations	3	18.95	6.32	0.61	
Residual	55	570.41	10.37		
Strategy (ST)	1	857.77	857.77	69.13	<.01
Residual	11	136.49	12.41		
Condition (C)	1	530.97	530.97	16.26	<.01
Residual	11	359.18	32.65		
L x ST	5	117.92	23.58	1.97	
Linear	1	111.82	111.82	9.32	<.01
Quadratic	1	2.21	2.21	0.18	
Deviations	3	3.89	1.30	0.11	
Residual	55	659.66	11.99		
L x C	5	60.05	12.01	0.92	
Linear	1	14.45	14.45	1.11	
Quadratic	1	21.00	21.00	1.61	
Deviations	3	24.60	8.20	0.63	
Residual	55	717.27	13.04		
ST x C	1	5.70	5.70	0.18	
Residual	11	345.79	31.44		
L x ST x C	5	47.02	9.40	1.35	
Linear	1	4.96	4.96	0.71	
Quadratic	1	2.09	2.09	0.30	
Deviations	3	39.97	13.33	1.91	
Residual	55	383.36	6.97		
Total	287	7038.70			

Appendix 5.1

Motor Ability Scores

Experiment 4

	Age Group 8	10	12
Male			
	4.9	9.0	14.3
	7.2	10.0	13.2
	12.3	10.7	13.9
	10.9	9.2	15.0
	9.3	11.8	15.4
	6.3	8.3	13.9
Mean	8.5	9.8	14.3
SD	2.8	1.3	0.8
Female			
	7.3	9.1	11.9
	5.9	9.8	12.2
	2.9	13.0	16.5
	5.4	12.6	9.7
	7.6	6.8	12.5
	3.0	10.3	8.0
Mean	5.3	10.3	11.8
SD	2.1	2.3	2.9
Total			
Mean	6.9	10.0	13.1
SD	2.9	1.8	2.4

Appendix 5.2

Motor Ability Scores Analysis of Variance

Experiment 4

Source	DF	SS	MS	F	P
Age	2	226.90	113.45	24.31	<.001
Sex	1	27.13	27.13	5.81	<.05
Age x Sex	2	21.92	10.96	2.35	
Residual	30	140.02	4.67		
Total	35	415.97	11.88		

Appendix 5.3

Residual Error

Experiment 4

Subject	Age	Sex	Condition			
			VVD	KKD	VVL	KKL
1	8	F	19.3	26.4	14.9	22.3
2	8	M	9.1	25.7	13.1	18.5
3	8	M	8.9	19.9	10.2	18.3
4	8	M	7.8	17.3	11.5	18.7
5	8	F	13.5	14.8	13.8	19.1
6	8	F	18.0	17.5	23.6	24.3
7	8	M	9.0	18.1	5.1	18.4
8	8	M	11.8	15.3	17.0	15.9
9	8	F	14.3	11.9	8.1	18.8
10	8	F	15.2	17.5	20.1	19.5
11	8	F	14.6	17.3	11.7	25.2
12	8	M	13.9	19.0	23.8	20.4
Group Mean			**13.0**	**18.4**	**14.4**	**20.0**
13	10	M	10.3	17.1	7.6	16.3
14	10	M	7.2	14.9	8.8	13.9
15	10	F	8.3	14.6	9.5	16.1
16	10	F	13.4	25.6	5.3	17.1
17	10	F	10.1	26.2	5.4	21.3
18	10	M	9.9	15.2	8.3	20.3
19	10	F	9.7	24.5	8.8	10.8
20	10	F	14.0	21.7	13.6	18.8
21	10	M	19.7	27.5	17.7	23.5
22	10	F	7.9	17.0	14.5	22.1
23	10	M	7.3	22.1	8.2	17.3
24	10	M	10.6	22.2	8.4	18.7
Group Mean			**10.7**	**20.7**	**9.7**	**18.0**

Appendix 5.3 (Continued)

25	12	M	7.9	11.7	5.6	13.9
26	12	M	10.3	13.2	6.3	15.8
27	12	M	10.3	16.1	9.0	12.6
28	12	F	9.8	9.6	8.1	15.0
29	12	F	8.7	16.6	6.0	13.8
30	12	M	8.9	14.4	7.9	17.0
31	12	M	8.5	14.0	9.4	13.3
32	12	F	8.3	12.3	3.6	10.0
33	12	F	11.1	18.7	3.3	16.8
34	12	M	9.5	16.6	10.6	15.8
35	12	F	13.5	26.0	2.6	20.8
36	12	F	14.2	24.8	9.5	20.0
Group Mean			**10.1**	**16.2**	**6.8**	**15.4**
Total Mean			**11.3**	**18.4**	**10.3**	**17.8**

Appendix 5.4

Residual Error Analysis of Variance

Experiment 4

Source	DF	SS	MS	F	P
Age (A)	2	454.08	227.04	7.75	<.005
Sex (S)	1	47.37	47.37	1.62	
A x S	2	28.08	14.04	0.48	
Residual	30	878.43	29.28		
Modality (M)	1	1934.31	1934.31	162.83	<.001
A x M	2	81.90	40.95	3.45	<.05
S x M	1	0.49	0.49	0.04	
A x S x M	2	55.81	27.90	2.35	
Residual	30	356.39	11.88		
Strategy (ST)	1	22.78	22.78	2.08	
A x ST	2	94.98	47.49	4.30	<.05
S x ST	1	16.79	16.79	1.53	
A x S x ST	2	22.31	11.15	1.02	
Residual	3	328.28	10.94		
M x ST	1	0.94	0.94	0.17	
A x M x ST	2	25.97	12.99	2.30	
S x M x ST	1	16.83	16.83	2.98	
A x S x M x ST	2	45.66	22.83	4.04	<.05
Residual	30	169.36	5.65		

Appendix 5.5

Residual Error Analysis of Variance for 8, 10 and 12-year-old Children

Experiment 4

Source	DF	SS	MS	F	P
Age (A)	2	2269.61	1134.80	7.85	<.005
Residual	33	4769.57	144.53		
Strategy (ST)	1	113.90	113.90	2.04	
A x ST	2	475.08	237.54	4.26	<.05
Residual	33	1838.18	55.70		
Modality (M)	1	9670.98	9670.98	154.65	<.001
A x M	2	409.61	204.80	3.28	
Residual	33	2063.60	62.53		
Length (L)	4	1384.90	346.23	9.78	<.001
Linear	1	1034.85	1034.85	29.22	<.001
Quadratic	1	189.44	189.44	5.35	<.05
Deviations	2	160.61	80.31	2.27	
A x L	8	569.83	71.23	2.01	
Linear	2	260.37	130.18	3.68	<.05
Quadratic	2	62.38	31.19	0.88	
Deviations	4	247.09	61.77	1.74	
Residual	132	4674.68	35.41		
ST x M	1	4.78	4.78	0.14	
A x ST x M	2	129.84	64.92	1.85	
Residual	33	1160.01	35.15		
ST x L	4	407.99	102.00	3.20	<.05
Linear	1	296.49	296.49	9.29	<.005
Quadratic	1	1.97	1.97	0.06	
Deviations	2	109.53	54.76	1.72	

Appendix 5.5 (Continued)

A x ST x L	8	569.19	71.15	2.23	<.05
Linear	2	419.69	209.84	6.58	<.005
Quadratic	2	112.50	56.25	1.76	
Deviations	4	37.00	9.25	0.29	
Residual	132	4211.48	31.91		
M x L	4	524.20	131.05	4.17	<.005
Linear1	1	234.23	234.23	7.46	<.01
Quadratic	1	121.66	121.66	3.87	
Deviations	2	168.31	84.15	2.68	
A x M x L	8	89.18	11.15	0.35	
Linear	2	7.71	3.86	0.12	
Quadratic	2	25.94	12.97	0.41	
Deviations	4	55.52	13.88	0.44	
Residual	132	4145.08	31.40		
ST x M x L	4	183.56	45.89	1.47	
Linear	1	57.64	57.64	1.84	
Quadratic	1	104.75	104.75	3.35	
Deviations	2	21.17	10.59	0.34	
A x ST x M x L	8	135.88	16.98	0.54	
Linear	2	28.60	14.30	0.46	
Deviations	6	107.28	17.88	0.57	
Residual	132	4128.00	31.27		
Total	719	43929.12			

Appendix 5.6

Residual Error Analysis of Variance for 10 and 12-year-old Children

Experiment 4

Source	DF	SS	MS	F	P
Age (A)	1	846.36	846.36	6.21	<.05
Residual	22	3000.60	136.39		
Strategy (ST)	1	453.30	453.30	7.61	<.05
A x ST	1	0.54	0.54	0.01	
Residual	22	1309.95	59.54		
Modality (M)	1	8174.60	8174.60	164.68	<.001
A x M	1	102.47	102.47	2.06	
Residual	22	1092.06	49.64		
Length (L)	4	1558.25	389.56	12.07	<.001
Linear	1	1195.57	1195.57	37.03	<.001
Quadratic	1	66.92	66.92	2.07	
Deviations	2	295.76	147.88	4.58	<.05
A x L	4	142.48	35.62	1.10	
Linear	1	53.14	53.14	1.65	
Quadratic	1	34.33	34.33	1.06	
Deviations	2	55.01	27.51	0.85	
Residual	88	2841.13	32.29		
ST x M	1	5.31	5.31	0.26	
A x ST x M	1	129.02	129.02	6.20	<.05
Residual	22	457.95	20.82		
ST x L	4	783.07	195.77	6.12	<.001
Linear	1	663.72	663.72	20.75	<.001
Quadratic	1	6.94	6.94	0.22	
Deviations	2	112.41	56.21	1.76	

Appendix 5.6 (Continued)

A x ST x L	4	86.16	21.54	0.67	
Linear	1	8.76	8.76	0.27	
Quadratic	1	69.63	69.63	2.18	
Deviations	2	7.77	3.88	0.12	
Residual	88	2814.58	31.98		
M x L	4	389.49	97.37	2.88	<.05
Linear	1	160.93	160.93	4.75	<.05
Quadratic	1	101.66	101.66	3.00	
Deviations	2	126.90	63.45	1.87	
A x M x L	4	46.22	11.56	0.34	
Linear	1	7.60	7.60	0.22	
Quadratic	1	22.47	22.47	0.66	
Deviations	2	16.15	8.08	0.24	
Residual	88	2978.61	33.85		
ST x M x L	4	172.79	43.20	1.73	
Linear	1	81.88	81.88	3.29	
Quadratic	1	89.29	89.29	3.58	
Deviations	2	1.62	0.81	0.03	
A x ST x M x L	4	79.87	19.97	0.80	
Linear	1	4.23	4.23	0.17	
Deviations	3	75.64	25.21	1.01	
Residual	88	2193.21	24.92		
Total	479	29658.02			

Appendix 5.7
Residual Error
Experiment 5

Subject	Age	Sex	Condition			
			VKD	KVD	VKL	KVL
1	8	F	19.1	23.8	18.3	32.0
2	8	M	20.6	16.0	19.2	16.5
3	8	M	10.6	18.6	15.1	16.8
4	8	M	13.6	23.9	13.6	22.8
5	8	F	15.7	30.8	11.7	30.5
6	8	F	22.3	25.0	18.6	45.2
7	8	M	13.4	12.6	10.1	11.9
8	8	M	14.6	14.5	16.6	23.2
9	8	F	15.4	25.6	14.9	17.1
10	8	F	15.5	19.1	29.9	15.7
11	8	F	18.2	17.1	12.7	41.2
12	8	M	18.7	14.4	17.9	32.6
Group Mean			**16.5**	**20.1**	**16.5**	**25.5**
13	10	M	16.1	15.8	17.0	20.5
14	10	M	16.5	10.0	12.1	19.5
15	10	F	17.8	23.1	17.4	19.8
16	10	F	16.9	21.5	23.6	16.4
17	10	F	15.2	23.0	9.7	9.1
18	10	M	22.1	10.0	13.1	18.6
19	10	F	18.0	8.3	11.1	10.6
20	10	F	14.4	13.9	11.2	17.9
21	10	M	16.5	20.4	21.0	18.4
22	10	F	19.1	15.4	21.3	16.1
23	10	M	9.1	11.2	9.9	14.9
24	10	M	13.2	18.2	12.3	17.6
Group Mean			**16.2**	**15.9**	**15.0**	**16.6**

Appendix 5.7 (Continued)

25	12	M	13.3	8.0	13.1	13.0
26	12	M	12.7	15.3	7.5	7.5
27	12	M	15.3	15.0	10.8	21.6
28	12	F	18.9	14.6	10.5	13.9
29	12	F	10.3	13.2	8.6	11.0
30	12	M	17.2	16.7	17.7	16.6
31	12	M	16.9	8.1	15.6	16.3
32	12	F	16.8	17.3	6.9	8.9
33	12	F	18.7	15.3	15.1	19.0
34	12	M	14.0	28.2	7.9	16.1
35	12	F	15.3	24.8	9.9	25.2
36	12	F	24.8	22.9	17.4	21.0
Group Mean			**16.2**	**16.6**	**11.8**	**15.8**
Mean			**16.3**	**17.6**	**14.4**	**19.3**

Appendix 5.8

Residual Error Analysis of Variance

Experiment 5

Source	DF	SS	MS	F	P
Age (A)	2	561.26	280.63	7.04	<.005
Sex (S)	1	225.25	225.25	5.65	<.05
A x S	2	145.44	72.72	1.83	
Residual	30	1195.45	39.85		
Presentation Modality (PM)	1	338.44	338.44	12.13	<.005
A x PM	2	203.20	101.60	3.64	<.05
S x PM	1	32.07	32.07	1.15	
A x S x PM	2	82.77	41.39	1.48	
Residual	30	837.31	27.91		
Strategy (ST)	1	0.12	0.12	0.01	
A x ST	2	168.47	84.24	4.88	<.05
S x ST	1	18.29	18.29	1.06	
A x S x ST	2	34.03	17.01	0.99	
Residual	30	517.47	17.25		
PM x ST	1	118.48	118.48	4.66	<.05
A x PM x S	2	16.16	8.08	0.32	
S x PM x ST	1	0.92	0.92	0.04	
A x S x PM x ST	2	41.11	20.55	0.81	
Residual	30	762.57	25.42		

Appendix 5.9

Residual Error Analysis of Variance for 8, 10 and 12-year-old Children

Experiment 5

Source	DF	SS	MS	F	P
Age (A)	2	2804.59	1402.30	5.91	<.01
Residual	33	7830.96	237.30		
Strategy (ST)	1	0.63	0.63	0.01	
A x ST	2	842.31	421.16	4.88	<.05
Residual	33	2848.65	86.32		
Modality (M)	1	1691.30	1691.30	11.72	<.005
A x M	2	1015.89	507.95	3.52	<.05
Residual	33	4760.63	144.26		
Length (L)	4	1550.45	387.61	8.83	<.001
Linear	1	1434.70	1434.70	32.67	<.001
Quadratic	1	48.79	48.79	1.11	
Deviations	2	66.96	33.48	0.76	
A x L	8	966.88	120.86	2.75	<.01
Linear	2	531.39	265.70	6.05	<.005
Quadratic	2	27.42	13.71	0.31	
Deviations	4	408.07	102.02	2.32	
Residual	132	5795.94	43.91		
ST x M	1	592.43	592.43	4.86	<.05
A x ST x M	2	80.82	40.41	0.33	
Residual	33	4023.57	121.93		
ST x L	4	63.59	15.90	0.38	
Linear	1	1.12	1.12	0.03	
Quadratic	1	46.06	46.06	1.11	
Deviations	2	16.41	8.21	0.20	

Appendix 5.9 (Continued)

A x ST x L	8	517.33	64.67	1.55	
Linear	2	371.94	185.97	4.47	<.05
Quadratic	2	1.81	0.90	0.02	
Deviations	4	143.58	35.90	0.86	
Residual	132	5493.11	41.61		
M x L	4	586.71	146.68	3.69	<.01
Linear	1	481.53	481.53	12.12	<.001
Quadratic	1	0.80	0.80	0.02	
Deviations	2	104.37	52.19	1.31	
A x M x L	8	353.51	44.19	1.11	
Linear	2	104.47	52.24	1.32	
Quadratic	2	62.09	31.05	0.78	
Deviations	4	186.94	46.74	1.18	
Residual	132	5243.05	39.72		
ST x M x L	4	8.22	2.05	0.06	
Linear	1	0.56	0.56	0.02	
Quadratic	1	3.91	3.91	0.12	
Deviations	2	3.75	1.87	0.06	
A x ST x M x L	8	322.36	40.30	1.22	
Linear	2	134.63	67.32	2.04	
Deviations	6	187.73	31.29	0.95	
Residual	132	4357.34	33.01		
Total	719	51750.26			

Appendix 5.10

Residual Error Analysis of Variance for 10 and 12-year-old Children

Experiment 5

Source	DF	SS	MS	F	P
Age (A)	1	85.23	85.23	0.45	
Residual	22	4162.66	189.21		
Strategy (ST)	1	246.10	246.10	3.36	
A x ST	1	163.94	163.94	2.24	
Residual	22	1612.23	73.28		
Modality (M)	1	253.20	253.20	2.68	
A x M	1	79.58	79.58	0.84	
Residual	22	2076.81	94.40		
Length (L)	4	349.53	87.38	2.24	
Linear	1	318.80	318.80	8.16	<.01
Quadratic	1	10.09	10.09	0.26	
Deviations	2	20.63	10.32	0.26	
A x L	4	165.98	41.50	1.06	
Linear	1	18.78	18.78	0.48	
Quadratic	1	8.27	8.27	0.21	
Deviations	2	138.93	69.46	1.78	
Residual	88	3438.03	39.07		
ST x M	1	237.11	237.11	3.54	
A x ST x M	1	20.74	20.74	0.31	
Residual	22	1473.78	66.99		

Appendix 5.10 (Continued)

ST x L	4	225.67	56.42	1.58	
Linear	1	142.20	142.20	3.98	<.05
Quadratic	1	26.04	26.04	0.73	
Deviations	2	57.43	28.71	0.80	
A x ST x L	4	61.90	15.47	0.43	
Linear	1	4.87	4.87	0.14	
Quadratic	1	1.23	1.23	0.03	
Deviations	2	55.79	27.90	0.78	
Residual	88	3146.62	35.76		
M x L	4	311.11	77.78	2.66	<.05
Linear	1	276.60	276.60	9.45	<.005
Quadratic	1	1.49	1.49	0.05	
Deviations	2	33.02	16.51	0.56	
A x M x L	4	300.01	75.00	2.56	<.05
Linear	1	99.51	99.51	3.40	
Quadratic	1	61.37	61.37	2.10	
Deviations	2	139.13	69.56	2.38	
Residual	88	2576.32	29.28		
ST x M x L	4	65.62	16.41	0.59	
Linear	1	37.73	37.73	1.36	
Quadratic	1	0.00	0.00	0.00	
Deviations	2	27.89	13.95	0.50	
A x ST x M x L	4	136.64	34.16	1.23	
Linear	1	42.85	42.85	1.54	
Deviations	3	93.79	31.26	1.13	
Residual	88	2443.76	27.77		
Total	479	23632.56			

Appendix 6.1

Motor Ability Scores

Experiment 6

Subject	Clumsy	Control
1	9.7	7.9
2	7.5	12.9
3	13.6	15.8
4	7.6	12.2
5	7.8	12.1
6	2.0	13.2
7	11.2	12.8
8	8.2	14.5
9	3.0	10.1
10	7.1	14.0
11	3.4	10.7
12	6.7	12.5
13	3.8	14.0
14	9.0	12.9
15	9.7	14.0
Mean	7.4	12.6
SD	3.2	1.9

Appendix 6.2

Intelligence Scores

Experiment 6

	Clumsy			Control		
Subject	**VIQ**	**PIQ**	**FSIQ**	**VIQ**	**PIQ**	**FSIQ**
1	85	100	91	98	104	101
2	128	111	123	101	111	105
3	118	126	124	109	120	116
4	120	114	120	117	123	122
5	105	101	102	103	98	101
6	85	87	83	107	118	113
7	90	98	92	97	81	88
8	82	74	77	113	106	111
9	81	91	85	82	101	90
10	105	98	101	119	120	122
11	95	75	84	113	111	113
12	115	108	113	111	115	114
13	85	105	93	88	93	90
14	107	120	114	113	112	114
15	97	96	96	107	114	111
Mean	100	100	100	105	108	107
SD	15	15	16	10	12	11

Appendix 6.3
Residual Error
Experiment 6

Subject	VVL	KKL	VKL	KVL
		Condition		
CONTROL				
1	5.3	15.1	6.5	16.4
2	7.6	21.4	15.1	21.4
3	3.4	17.9	11.4	23.4
4	3.5	17.4	14.8	15.2
5	8.8	22.8	20.7	19.6
6	5.2	26.0	15.3	38.2
7	7.7	15.6	15.0	15.8
8	7.6	19.1	10.7	21.8
9	6.9	20.2	19.8	23.3
10	20.2	23.3	14.4	19.2
11	5.2	19.9	26.1	25.4
12	9.8	16.4	14.1	19.0
13	5.5	21.0	17.9	35.8
14	7.6	16.8	21.1	18.0
15	7.8	15.7	11.2	15.6
Mean	**7.5**	**19.2**	**15.6**	**21.9**
SD	**4.0**	**3.2**	**4.9**	**6.9**
CLUMSY				
1	20.2	21.0	15.0	22.8
2	8.9	17.9	15.2	17.2
3	11.3	17.0	24.8	22.3
4	13.1	27.6	21.4	31.2
5	14.8	25.4	22.1	31.3
6	47.9	38.8	26.3	35.7
7	7.1	22.7	19.5	18.6
8	8.0	16.6	15.3	23.7
9	25.1	26.6	17.0	45.1
10	14.5	33.1	25.8	41.7
11	24.9	22.8	20.7	30.7
12	25.3	19.3	24.1	33.4
13	19.8	16.3	23.6	20.9
14	10.3	16.3	27.7	27.6
15	16.6	22.2	17.8	19.2
Mean	**17.8**	**22.9**	**21.1**	**28.1**
SD	**10.4**	**6.6**	**4.3**	**8.5**
Mean	**12.7**	**21.1**	**18.3**	**25.0**
SD	**9.4**	**5.4**	**5.3**	**8.2**

Appendix 6.4

Residual Error Analysis of Variance

Experiment 6

Source	DF	SS	MS	F	P
Group (G)	1	6206.11	6206.11	14.11	<.001
Residual	28	12316.89	439.89		
Length (L)	4	268.26	67.06	0.98	
Linear	1	128.86	128.86	1.88	
Quadratic	1	84.88	84.88	1.24	
Deviations	2	54.51	27.26	0.40	
G x L	4	127.41	31.85	0.46	
Linear	1	54.09	54.09	0.79	
Quadratic	1	35.23	35.23	0.51	
Deviations	2	38.09	19.05	0.28	
Residual	112	7678.01	68.55		
Translation (T)	1	3444.59	3444.59	22.52	<.001
G x T	1	52.61	52.61	0.34	
Residual	28	4283.43	152.98		
Modality (M)	1	8486.62	8486.62	58.72	<.001
G x M	1	334.12	334.12	2.31	
Residual	28	4046.93	144.53		
L x T	4	622.51	155.63	1.82	
Linear	1	581.95	581.95	6.80	<.05
Quadratic	1	2.94	2.94	0.03	
Deviations	2	37.62	18.81	0.22	
G x L x T	4	57.85	14.46	0.17	
Linear	1	38.07	38.07	0.44	
Quadratic	1	1.18	1.18	0.01	
Deviations	2	18.60	9.30	0.11	
Residual	112	9585.47	85.58		

Appendix 6.4 (Continued)

L x M	4	101.29	25.32	0.40	
Linear	1	26.98	26.98	0.42	
Quadratic	1	28.51	28.51	0.45	
Deviations	2	45.80	22.90	0.36	
G x L x M	4	213.97	53.49	0.84	
Linear	1	50.33	50.33	0.79	
Quadratic	1	116.00	116.00	1.82	
Deviations	2	47.65	23.82	0.37	
Residual	112	7174.25	63.81		
T x M	1	118.35	118.35	1.07	
G x T x M	1	516.04	516.04	4.66	<.05
Residual	28	3098.88	110.67		
L x T x M	4	107.72	26.93	0.39	
Linear	1	13.16	13.16	0.19	
Quadratic	1	84.07	84.07	1.23	
Deviations	2	10.50	5.25	0.08	
G x L x T x M	4	229.43	57.36	0.84	
Linear	1	52.18	52.18	0.76	
Deviations	3	177.25	59.08	0.86	
Residual	112	7651.53	68.32		
Total	599	76695.27			

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