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Underlying deficits in motor and language impairments in children

Dr. polit –avhandling 2002
Program for idrettsvitenskap
Fakultet for samfunnsvitenskap og teknologiledelse
Norges teknisk-naturvitenskapelige universitet, NTNU
Trondheim

ISBN 82-471-5121-9

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Acknowledgements

The work with this thesis was carried out at the Programme of Sport Sciences, Norwegian University of Science and Technology (NTNU), and was financed by NTNU in the form of a scholarship. I wish to thank all those who in one way or another have contributed to the completion of this thesis. I give my special thanks to John Whiting who was my mentor and who has been tutoring the work with the thesis in an excellent way. His engagement, perfection and punctuality constituted a good example. Unfortunately, he did not live long enough to see the whole thesis completed. I also wish to express my gratitude to Rolf Ingvaldsen, who did not hesitate to take over the full responsibility as a mentor after John died, and who always provided his assistance whenever needed, in particular during the final important stage in the work with the completion of the thesis. Further, I would like to express my thanks to the following people.

- Hermundur Sigmundsson, for his constant enthusiasm and engagement in the project, for participating in data collection and for introducing me to the magnocellular theory.
- Turid Hønnås for being very helpful in the subject selection stage.
- Arne Valberg and Inger Rudvin, for sharing with me their knowledge about magno- and parvocellular cells.
- Joel Talcott, for giving me accesses to the psychophysical tests of visual perception and for participating in the data collection.
- Geir Oterhals and Paul Jarle Mork, for designing parts of the apparatus used in the ball-catching study.
- Tore Kristian Aune, for administrating the ProReflex recordings.
- Gertjan Ettema, for his assistance in MatLab analyses of the ProReflex data.
- Kyrre Svarva, for giving good advice on statistical matters.
- The hovedfagstudents Monica Haga and Ann Kristin Forseth and the physiotherapy students Marthe Volden and Anne Skarland for their assistance with MABC-screening.
- Ragnhild Sand for organising the literature in the initial stages.
- My co-student Anne Torhild Klomsten, for her friendship and for many interesting discussions on scientific as well as non-scientific matters.

I wish to thank all the children who participated as subjects, their parents who gave their consent, and their teachers as well as those in the school administration for their co-operation. I am grateful to everyone in the Programme of Sport Sciences who have been good and supporting colleagues and who have contributed to make me feel comfortable in the role as a PhD student.

Finally, I wish to thank my boyfriend, Torvid Pettersen, for providing personal as well as financial support, and our daughter Maja, for reminding me that there are more important things in life than a PhD thesis.

List of papers

- Paper 1: Estil, L.B. & Whiting, H.T.A. (2001). Motor/language impairment syndromes – direct or indirect foundations? In: S. Cermak and D. Larkin (Eds.), *Developmental Co-ordination Disorder*. Albany, NY: Delmar Thomson Learning.
- Paper 2: Estil, L.B., Whiting, H.T.A., Sigmundsson, H., & Ingvaldsen, R.P. (2003). Why might language and motor impairments occur together? Accepted for publication in the journal *Infant and Child Development*.
- Paper 3: Estil, L.B. & Whiting, H.T.A. (2002). The validity of the inter/intra hemispheric deficit hypothesis as an explanation of the co-occurrence of motor and language impairments. *Experimental Brain Research*, 143, 126-129.
- Paper 4: Estil, L.B., Ingvaldsen, R.P and Whiting, H.T.A. (2002). Spatial and temporal constraints on performance in children with movement co-ordination problems. Accepted for publication in the journal *Experimental Brain Research*.
- Paper 5: Estil, L.B. Visual versus proprioceptive explanations of poor movement co-ordination in children. (Research note, in extension of paper 4). In preparation for scientific publication.
- Paper 6: Estil, L.B., Sigmundsson, H. & Talcott, J. Are motor and reading impairments in children related to the same, or different, visual deficits? In preparation for scientific publication.

(Note: Papers 1-6 correspond to the Chapters 1-6)

Preface

Children who, for some reason, are inferior in performance to their peers in certain domains of development often experience the feeling of falling short. This applies to children who are poor in motor skills and/or in academic skills such as spoken and written language. Although a relatively small group of children is affected by such problems, the problems may have serious implications for those concerned. Some children seem to be affected in the motor domain only, while others seem to experience problems only with relation to spoken and/or written language. Still, the coincidence of motor and language/writing impairments in children is considerable, and too large to be fortuitous. It is believed that intervention and prevention programs will be more effective if based upon knowledge about underlying sources of the observed problems. The aim of the present thesis, therefore, is to do a theoretical and empirical investigation of putative underlying sources of language (including both oral language and reading) and motor impairments in children, from a neuropsychological perspective.

To that end, Chapter 1 provides a theoretical introduction to the theme motor/language impairment syndromes and presents different theoretic explanations that has been suggested in the literature, as to why such syndromes often co-occur. From a social scientific point of view, these syndromes may be regarded as *indirectly* linked mediated by social constraints such as, for example, self-esteem. However, from a neuropsychological perspective, language and motor impairments in children are regarded as *directly* related, due to a developmental lag or a deficit in the nervous system. That will be the main focus of the present thesis. From this perspective, several underlying neurological deficits that could account for language as well as motor impairments have been suggested. These are related to different neurological sites such as, for example, the *cerebellum* and the *corpus callosum*. Cerebellar explanations have been invoked to account for postural problems in language impaired children and dyslexics as well as temporal problems in both the motor and language domains. Bimanual co-ordination problems and other laterality problems observed in dyslexics, language impaired children as well as motor impaired children have been attributed to callosal dysfunction. A more recent theoretical explanation is the *magnocellular* theory, related to a certain kind of fast conducting nerve cells that

bring information from the retina to the visual cortex. This theory was, originally, introduced as an explanatory factor of dyslexia, but was later suggested to play a role in motor impairment as well.

Chapter 2 reports an exploratory study using quantitative and qualitative methods in attempt to identify putative neurological deficiencies that may account for the co-occurrence of motor and cognitive (measured as psycholinguistic abilities) impairments in a sample (N = 15) of 6-10 years old (oral) language impaired children. A subgroup of n = 4 children that are weak in both language and cognitive functions is identified. The cerebellar deficit hypothesis and the inter/intra-hemispheric deficit hypothesis are discussed as candidate explanations.

The inter- versus intra-hemispheric deficit hypothesis is further validated in Chapter 3. The same subgroup of four children as that identified in Chapter 2 is tested on two different movement tasks designed to measure inter- and intra-hemispheric functions. The results are discussed in the light of Liederman's shielding model. This model emphasises the role of the corpus callosum in shielding information between the hemispheres, which is necessary in order to allow for independent processing.

In Chapter 4 the focus shifts to motor co-ordination problems *per se*. A task that is particularly difficult for children with poor motor co-ordination, is that of catching a ball, a task imposed by severe spatial and temporal constraints. It is believed that information about where this task breaks down, at the spatial or temporal component, will provide clues as to what could be the underlying causes of the co-ordination problems. In order to separate out the temporal and spatial aspects of the catching task, two experiments are designed, one emphasising the reaching action (spatial orientation), the other emphasising the grasping action (imposed by temporal constraints). The performance of a sample (n = 8) of 10-11 year old children with poor motor skills is compared to that of an equal sized control group on these tasks. The temporal and spatial deficits discovered are discussed with relation to the distal and proximal proprioceptive systems as well as the visual system. The question whether the underlying problem is related to a visual or proprioceptive deficit, or to a combination of visual and proprioceptive deficits, is further explored in Chapter 5.

Chapter 5 is written as a Research Note in extension of Chapter 4, using the same subjects. The groups are compared on two tests of proprioception, designed for the purpose of measuring inter-/ and intra hemispheric information processing (same

tasks as those used in Chapter 3), and three different tests of visual perception, designed to measure magno- and parvocellular function. The results are discussed with relation to visual processing and maturation of the corpus callosum.

In Chapter 6 the visual perceptual problems suggested in Chapters 4 and 5 are investigated with relation to both motor and reading impairment on an extended group of 10-11 year old children. Three groups of $n = 8$ children are selected from a larger sample ($N = 102$), one group which is motor impaired only, one which is both motor and language impaired, as well as a normal control group. These groups are compared on the same visual tests (with the exclusion of one) as those used in Chapter 5. Based on the results from the group comparisons and a correlation analyses, magno- and parvocellular involvement in both motor and reading tasks, as well as in motor and reading impairments, is discussed.

Finally, Chapter 7 contains a summary and a general discussion that evaluates the theoretical positions presented in Chapter 1 in the light of the empirical studies reported in Chapters 2 – 6. Conclusions and suggestions for further studies are made.

Chapter 1

MOTOR/LANGUAGE IMPAIRMENT SYNDROMES - DIRECT OR INDIRECT FOUNDATIONS?

In most industrial countries increasing emphasis is being placed on education and young people are required to spend a significant part of their lives in school. The mastery of basic academic skills like reading and writing is considered fundamental to success. Nevertheless, much of their play and leisure time involves physical activity of one kind or another. In this context, the playground/sport field becomes important arenas for socialisation and the development of those social skills that are needed to function in a complex society.

Children who are below the normal rate of development in motor and language skills, in the following referred to as motor and language impaired,¹ may not only fail to meet the performance related academic standards of their school environment, but they may also lack the necessary physical competence to be accepted as equals in play activities demanding motor competence. This, in turn, may have detrimental effects on personal development, that is, the impairment(s) become(s) a handicap (World Health Organisation, 1980).

There is little consensus of opinion about what is normal development. This makes it difficult to identify impairments in children - particularly at an early age - and to establish meaningful identification criteria and cut-off points. This has resulted in different studies showing a range of 5-15% of school children (5 - 12 years) as exhibiting motor skill problems that are well below the norm (American Psychiatric Association, 1994; Brenner, Gillman, Zangwill, & Farrell 1967; Gubbay, 1975; Henderson & Hall, 1982; Mæland, 1992; Rutter, Graham, & Yule, 1970). According to most of these studies the incidence is higher in boys than in girls (Gubbay, 1978; Henderson & Hall, 1982; Keogh, Sugden, Reynard, & Calkins, 1979; Mæland, 1992). Motor impairment in children has, over the years, been assigned a variety of labels of which the following are some examples: developmental apraxia/disturbances in motor

¹ Impairment is a loss or abnormality of body structure or of a physiological or psychological function (World Health Organization, 1997).

planning (Orton, 1937), ataxia/unsteady or uncoordinated movement (Gubbay, 1975), clumsiness (Henderson, 1977), developmental dyspraxia/disorder of gesture (Dewey, 1995), and developmental co-ordination disorders (DCD)/motor impairment in the absence of neurological signs (American Psychiatric Association, 1994). Many of these terms have also been divided into subgroups. Apraxia, for example, has been classified as ideational when defective performance of sequences of gestures is the observed deficit and as ideomotor when disturbance is confined to isolated gestures (Dewey, 1995).

It has also been estimated that some 2-10% of similar age groups (but not necessarily the same children) exhibit different kinds of language problems, manifested in speech, reading and writing² (American Psychiatric Association, 1994; Gaddes, 1985; Rutter, 1978; Stein, 1994; Stevenson, 1984). Once again, boys would seem to be more affected than girls (Bjørger, Undheim, Nordvik, & Romslo, 1987; Edwards, Ellams, & Thompson, 1976; Gjessing, Nygaard, & Solheim, 1988; Lambe, 1999; Rutter & Yule, 1975; Silva, McGee, & Williams, 1985; Stein, 1994). Some of these children experience problems related to both motor and language skills. An overlap of 40-70% in this respect has been indicated in the literature (Nickisch, 1998; Paul, Cohen, & Caparulo, 1983; Rintala, Pienimäki, Ahonen, Cantell, & Kooistra, 1998; Wolff, Melngailis, Obregon, & Bedrosian, 1995). Given that such an overlap is unlikely to be fortuitous, it is this group of children on which attention will be particularly focused in this Chapter.

In some cases the coexistence of motor and language problems may be related to the overall condition. For example, a general problem in the organisation of movements may also manifest itself in the fine co-ordination required for speech, resulting in articulation problems. Yet, other language difficulties may exist which are less obviously related to the motor problems *per se*, for example, putting thoughts into words or finding the right words and organising them into coherent sentences. The picture becomes even more complex when problems related to, for example, phonological dyslexia are shown to go hand-in-hand with certain kinds of motor problem, for example, bimanual co-ordination (Moore, Brown, Markee, Theberge, &

² The language problems referred to in the literature are fairly diffuse encompassing problems in speech, reading and writing as well as diverse kinds of dyslexia.

Zvi, 1996). Where such problems occur together they may be mediated directly or indirectly.

The notion of a direct mediation implies that both problems are simply different manifestations of one underlying substrate, for example, a dysfunctional neurological system brought about by a maturational delay or damage to the CNS. Indirect mediation, in contrast, implies that there is one primary problem, either motor or language, and the secondary related problem, either language or motor, arises as a consequence of social constraints to which the primary problem gives rise.

1.1 Indirect/direct mediations

The play arena is important for the development of both motor and language skills. Children who have poor motor skills often experience difficulty in being accepted as participants in play with other children (Schoemaker & Kalverboer, 1994). Similar problems are also reported in children who are inadequate in language skills (Brinton, Fujiki, Spencer, & Robinson, 1997). When children are excluded from interacting with other children, for either reason, this may have a negative effect on the development of both motor and language skills. In such cases motor and language problems may be indirectly linked via social constraints. The result is a vicious circle where isolation due to motor or language incompetence leads to reduced participation and diminished opportunities for practising both motor and language skills. This, in turn, exacerbates both the motor and language problems.

One of the mediating factors, in this respect, may be self-esteem. The negative effect of motor and/or language impairments on self-esteem has been well-documented (Henderson, May, & Umney, 1989; Kalliopuska & Karila, 1987; O'Dwyer, 1987; Shaw, Levine, & Belfer, 1982; Van Rossum & Vermeer, 1990). Again, a vicious circle may be in operation. Low self-esteem stemming from problems with motor and language skills, may deter such children from engaging in social situations because of fear of failure which, in turn, leads to further delay in the development of either/or both (Harter, 1978). This Chapter will not be concerned to pursue the issue of indirect mediation further, at the same time it is appreciated that it is an issue with many social consequences that are of crucial importance.

Direct mediation between motor and language skills is, perhaps, easier to document. Although, on the surface, motor and language skills would seem to fall into quite distinct categories they share some basic characteristics that suggest that they be closely related in a number of ways. In the first place, language skill demand highly sophisticated movement skills, which manifest themselves in speech, reading and writing. For example, speech requires fine co-ordination of muscles in tongue, lips, jaw, larynx and respiratory organs. The complexity of this co-ordination is exemplified by the fact that, for a baby to say "ba," for example, it takes the co-ordinated action of about 40 muscles (Kelso, 1995). Motor processes are also fundamental to reading and writing. Reading requires finely controlled movements of the eyes, while writing requires fine well-co-ordinated movements of both the writing hand and the eyes.

However, it has to be appreciated that the terms motor and language skills are very general categorisations that subsume a variety of sub-skills and, to that extent, are too general to be of much help in coming to an understanding of why impairments in the performance of these skills should arise in the first place and why they might occur together in some children. For this reason the sub-categorisations speech/motor impairment and dyslexia/motor impairment will be two sub-categories that will need to be separately invoked from time to time in what follows. In so doing , the limitations of such a division have also to be kept in mind based as it is on the traditional view that dyspraxia (speech impairment) and dyslexia (reading impairment) are distinct clinical syndromes. More recent research findings have demonstrated that the vast majority of children identified in pre-school as developmentally language (speech) impaired exhibit inordinate difficulty in learning to read when they reach elementary school (Plaza, 1997; Tallal, Curtiss, & Kaplan, 1988). The speech impairment of those children who develop dyslexia is typically recognised as stemming from a phonological deficiency, which might be related to a more fundamental information-processing deficit. Thus, in many cases, younger children with phonological dyslexia are likely to be members of the same subgroup, while those speech impaired children who grow out of their problems represent yet another sub group.

1.2 Evolutionary Perspective

From an evolutionary perspective the development of both motor and speech skills are closely interrelated. For example, Rizzolatti and Arbib (1998), drawing on the earlier work of Kimura (for a review, see Kimura, 1993)³, argue that speech has developed from a sequence of events that began with gestural communication. The gist of their argument is as follows: The oro-facial gestures of primates were those most likely to be used in communication between individuals. The open-closed alternation of the mandible that is typical of oro-facial communication in monkeys appears to persist in humans where it forms the syllable frame in speech production. If manual gestures are associated with oro-facial communication the sender's possibilities dramatically increase. These considerations suggest that, at a certain stage, a brachio-manual communication system evolved complementing the oro-facial one. An object or event described gesturally (such as, large object - large gesture of the arms) could now be accompanied by vocalisation. If identical sounds were constantly used to indicate identical elements (such as large object, large opening of the mouth - vowel 'a' and small object, tiny opening of the mouth - vowel 'i'), a primitive vocabulary of meaningful sounds could start to develop. The evolutionary pressure for more complex (combinatorial) sound emission, and the anatomical possibility for it, were the elements that moved language from its manuo-brachial origins to sound emission. Manual gestures progressively lost their importance whereas, by contrast, vocalisation acquired autonomy until the relation between gestural and vocal communication inverted and gesture became purely an accessory factor to sound communication.

Rizzolatti and Arbib (1998) invoke Liberman's motor theory of speech (1993) and PET scan data (Schlaug, Knorr, & Seitz, 1994) in suggesting that both manual gestures and speech are related to different motor fields (hand, mouth and larynx) represented in Broca's area of the brain. Thus, Broca's area would appear to play a mediating role in both motor and speech skills, and could, therefore, be involved in impairments in either or both of these domains.

Identifying invariances in motor and language skills (whether these involve speech or reading), as Rizzolatti and Arbib have done, is one way in which to explore

³ According to Corballis (1998) this idea had already been proposed by Bonnot de Condillac during the eighteenth century and was simply revived by Hewes in 1973.

their relation more deeply. Another attempt of this nature, that has been well documented in the literature and which has particular relevance for the sub-category speech/motor impairments, is the putative common aetiology underlying aphasia and apraxia.

1.3 Aphasia and apraxia

The link between speech and gestural abilities is reflected in the neurological disorders aphasia and apraxia. Disruptions in speech which are experienced by individuals who have suffered damage to the central nervous system are called aphasias, and usually result from damage to the left cerebral hemisphere (Kimura, 1993). Another symptom of left hemisphere damage is manual apraxia, commonly defined as inability to carry out specified movements, despite good strength and mobility in the muscles or limbs which are affected. It is recognised that most apraxic patients are also aphasic, and the apraxia is commonly inferred from the failure to make the required movements to a verbal command (Kimura, 1993). Liepmann (1908) has suggested that aphasia and apraxia are essentially similar, and that both are manifestations of the loss of an ability to make certain kinds of movements.

The notion of a relation between gestural and language (speech) skills in children is supported by research findings of deficits of praxis in speech impaired children (Dewey & Wall, 1997). For example, Dewey and Wall (1997) studied gestural performance in 35 children, within the age-range 6 and 11 years, of which 15 (11 boys, 4 girls) were identified as speech and language impaired⁴ and 20 children (11 boys, 9 girls) served as a control group. These groups were compared on gestural performance, such as transitive limb gestures (i.e., brush teeth with a tooth brush), intransitive gestures (e.g., wave goodbye), transitive orofacial gestures (e.g., drink from a straw) and intransitive orofacial gestures (e.g., whistle) to command. Results showed that the speech and language impaired group performed significantly poorer than the control group on limb intransitive and orofacial intransitive gestures.

⁴ A child was defined as speech and language impaired if he/she demonstrated an impairment in speech articulation, voice or fluency, or deviant development of comprehension, or use of spoken, written or other symbol system that adversely affect educational performance. Children who demonstrated deficits only in articulation were not included.

The finding that the speech and language impaired children were also significantly poorer than the controls on memory tests led to the proposition that children with both speech and language impairments may be deficient in their motor acts because they lack both the language and verbal memory skills needed to encode motor acts into memory.

Similar studies of gestural hand and arm movements carried out by Hill (1998; Hill, Bishop & Nimmo-Smith, 1998) revealed a dyspraxic deficit in children (age range 7-13 years) with specific language impairments (SLI) only, children with both SLI and motor impairments, and in children with motor impairments only (developmental co-ordination disorders). One could question whether the problems of these three subgroups of children were due to the same basic deficit related to the left hemisphere, as they all showed similar praxis problems, or whether, despite this commonality, they suffer from slightly different underlying dysfunctions?

1.4 Fine Motor Skills

Motor skills have been commonly subdivided into fine and gross. In the present context this is a useful subdivision as problems in the performance of fine motor skills, in particular, have more often been associated with language problems whether these be in the speech or reading domains.

With respect to SLI, for example, a number of studies have identified a diversity of fine motor skill problems in a variety of different groups of speech impaired children involving: speed of peg-moving (Bishop & Edmundson, 1987; Owen & McKinlay, 1997; Powell & Bishop, 1992), threading beads and fastening buttons (Owen & McKinlay, 1997); posture production using hand and arm movements (Hill, 1998); associated movements accompanying hand and finger movements, for example hand-patting, hand pronation/supination, index-thumb opposition, sequential finger-opposition and diadokinesis (Notherdaeme, Amorosa, Ploog, & Scheimann, 1988). Although some of these studies (e.g., Powell & Bishop, 1992) provide evidence for a common aetiology, what is missing are detailed discussions about which neurological abnormalities might underlie such behaviours.

Where attempts have been made to highlight a common aetiology in motor and speech impairment more consistency in the findings would seem to be forthcoming

when the focus has been on fine motor co-ordination of hand and finger movements (Bradford & Dodd, 1996; Preis, Bartke, Willers, & Müller, 1995; Preis, Schittler, & Lenard, 1997). For example, Preis et al. (1995) found that even children with linguistically well defined grammatical SLI without significant articulatory deficits (11 children: 6-11 years) were impaired in complex fine motor skills. In a pegboard moving task eight of the SLI children needed significantly more total time with the right hand (all children were right handed) than the control group. Motor problems in the SLI children also increased with the complexity of the motor task. What might be the neurological implications of such deficits? Preis et al. (1995) concluded that the fine-motor skill problems might signal a sequencing and temporal order deficit, as SLI children not only experience temporal and sequencing problems related to motor tasks, but also have difficulties in processing successive stimuli presented rapidly in the auditory modality. They invoke the idea that both language and motor processes might be dependent on neuronal elements which are not specific to only one kind of process, but are responsible for modulation of specific components of the different processes. They suggested further, that the supplementary motor area might be involved, functional imaging studies having shown that this area is highlighted both in complex planning of sequenced motor processes (Deiber et al., 1991; Roland, Larsen, Lassen, & Skinhoj, 1980; Seitz et al., 1995) and during speech processes (Tamas, Schibasaki, Horikoshi, & Ohye, 1993).

Attempts of this nature have also been apparent in the context of dyslexia/motor impairments exemplified, particularly, in the so-called cerebellar hypothesis.

Cerebellar Hypothesis

Traditionally, the cerebellum has been considered to be a motor area (Eccles, Ito, & Szentagothai, 1967; Holmes, 1917, 1939; Stein & Glickstein, 1992). However, Ivry and colleagues (for a review, see Ivry, 1993) have suggested that it plays an important role, not only in motor control but also in perception of time. Cerebellar patients have been shown to be impaired in the performance of auditory time perception tasks as well as in repetitive finger tapping tasks (Ivry & Diener, 1991; Ivry & Keele, 1989; Keele, Ivry & Pokorny, 1987; Keele, Pokorny, Corcos, & Ivry, 1985). They put forward the hypothesis that the predominant role of the cerebellum in motor control is the control of fine timing, and that the computational capabilities of this structure are

not restricted to the motor domain, but are also accessible to non-motor tasks that are dependent on precise timing. They further proposed that there is no single timing mechanism in the cerebellum, but rather that this computational ability is distributed with different regions being involved with the particular category of temporal information utilised in different tasks.

Based on this hypothesis Fawcett and Nicolson (1995) suggested that both the motor and language related impairments observed in dyslexic subjects could be two different expressions of a single neurological deficit in the cerebellum. They found that groups of dyslexic children (N's ranging between 8 and 16 subjects and differing in age from 8 to 17 years) were significantly slower than their matched (age and IQ) controls and equivalent to their reading age controls in placing pegs and articulation rate, while for bead threading they were significantly slower than even their reading age controls.

Referring to these findings and other studies that have shown a significant relation between balance deficits, motor skill deficits, and timing deficits in dyslexic children they suggested that children with dyslexia might suffer from a minor damage to the cerebellum. Fawcett and Nicolson's hypothesis of a cerebellar deficit was supported by a later study (Fawcett, Nicolson, & Dean, 1996) in which dyslexic children showed highly significant impairments on a battery of clinical tests designed to detect cerebellar impairment (the test battery is described in Dow & Moruzzi, 1958). The tests included maintenance of posture (balance time and postural stability), hypotonia (reduced muscle tone), and complex movements (pointing to a bull's eye with a marker pen, finger to finger pointing, adiadokinesis, toe tap speed, placing the index finger and thumb of one hand onto the index finger and thumb of the other hand). Out of 29 dyslexic children all were impaired on arm displacement, 28 on postural stability, and 23 on finger/thumb opposition.

Despite the strong suggestive evidence of cerebellar impairment, these authors were well aware of the limitations of their findings, pointing to the fact that the evidence is only indirect and non-specific and to the possibility that research with different samples of children with dyslexia and control children might lead to lower estimates of effect size and incidence rate.

In an attempt to establish the generality of the results obtained in the 1996 study, a replication was recently carried out using larger samples of dyslexic and control children (Fawcett & Nicolson, 1999). The subjects in this study showed

similar impaired performance. The cerebellar hypothesis was further supported by another recent study (Nicolson et al., 1999) in which brain activation was monitored by positron emission tomography in matched groups of six dyslexic adults and six control subjects as they carried out either a pre-learned sequence or learned a novel sequence of finger movements. They found that brain activation was significantly lower for the dyslexic adults than for the controls in the right cerebellar cortex and the left cingulate gyrus when executing the pre-learned sequence, and in the right cerebellar cortex when learning the new sequence.

In the case of both speech/motor impairments and dyslexia/motor impairments the hypothetical neural explanations put forward still beg the question as to whether the neurological impairments peculiar to such areas are the consequence of neural damage, abnormal neural development or delayed maturation (a so-called developmental lag). The latter two kinds of explanation also give rise to questions about the relevant contributions of nature and nurture.

1.5 Developmental Lag or neurological impairment

The notion of a developmental lag builds on the maturational perspective of a delay in the acquisition of age related skills and implies that poor performance in language and motor skills are simply due to a genetically determined, slow maturation of the nervous system. If the language/motor impairments in children were due to a developmental lag it would be expected that they would overcome their problems as they grow older, as has been observed in children with motor impairments (Barnett & Henderson, 1992; Losse et al., 1991). However, if the problems should persist into adulthood (as is usually the case with dyslexia), an abnormal neural development, rather than a developmental lag *per se* might be assumed.

Some authors (Hill, 1998; Powell & Bishop, 1992) have suggested that the coexistence of speech and movement problems may simply be the result of a developmental lag, the motor performance (gesture production) of motor and speech impaired children being qualitatively similar to that of normally developing younger children. This standpoint, however, was not supported by an earlier study of

Notherdaeme et al. (1988) who found, in a sample of 17 speech impaired children⁵ (16 boys and one girl), in the age range 7-12 years, evidence for a deviant neural development, rather than a developmental lag *per se*, as associated movements in their speech impaired children were shown to be qualitatively different from those of younger control children (10 girls and 7 boys, 4-5 years). The fact that higher rates of left-handedness and ambidexterity are reported in children with speech impairment (Bishop, 1990) also strengthens the credibility of a deviant neural development hypothesis. At the same time, it has to be recognised that there are also many studies that have shown no association between handedness and speech impairment (Bishop, 1990; Preis et al., 1997). The reasons for this incongruity are difficult to pinpoint. They could be due to different characteristics of the groups involved in the studies, differences in the methods used for measuring laterality, or different subtypes.

Denckla and Rudel (See Denckla, 1985) have suggested that a maturational lag in relation to visual and perceptual abilities may be involved in dyslexia. This proposition was based on results from studies of dyslexic, otherwise learning disabled and normal children on the task of map walking (Denckla, Rudel, & Broman, 1980). Dots were placed on the floor, and subjects were required to follow a path mapped out in ink on a hand-held piece of cardboard, the route corresponding to that on the floor. They found that the younger dyslexic children (below the age of 10) had the worst performance of the three groups whereas, surprisingly, the teenaged dyslexic group demonstrated superior on this test. They concluded that the most parsimonious explanation was a maturational lag in that part of the 'motor analyser' that is dependent on the left hemisphere and has been found to be important for timed, sequential, detailed movements.

Although, as might be inferred from this study, reading disabled children may grow out of their motor problems (Denckla, 1985), there are reports of increasing differences with age between reading impaired and control subjects on tests of language (Wolf, 1980). Denckla's (1985) explanation of this finding was that even when there is lifelong deficiency of certain left-hemisphere-suberved capabilities, "those that are part of the motor analyser system in the left hemisphere may improve

⁵ The children were diagnosed as specific developmental speech and language disorder by a team of experienced speech/language therapists. All children, fifteen right handed and two left handed, attended the special school at the Max Planck Institute for Psychiatry, and had IQs within normal range, and no major neurological deficits.

sufficiently to act as means of expression for the adequate or even above average functioning of a presumably right hemisphere-subserved set of capabilities, such as athletics and perception of spatial relationships and visual design.”

An attempt to explain a retarded development of the left hemisphere, which might contribute to deviant laterality profiles, language and other learning disorders in children, is provided by the testosterone hypothesis of Geschwind and Galaburda (1985). This hypothesis holds that high testosterone levels in utero may slow down the development of the left hemisphere, and may also explain why language impairments and other learning disorders are more often observed in boys than in girls.

With respect to motor impairment Sigmundsson et al. (Sigmundsson, Ingvaldsen, & Whiting, 1997b) found evidence indicative of a developmental lag as the performance of 8-year old children with hand eye- co-ordination problems was similar to 5-year old controls in inter- and intra- sensory modality matching. However, when scores for the preferred and non-preferred hands were analysed separately, only the children with hand eye co-ordination problems showed significant performance differences, in favour of the preferred hand in both conditions where proprioception was involved. They suggested that the developmental lag exhibited by these children might have pathological overtones related to the development of the corpus callosum, which generally is considered to reach its final stage of maturation between 5 and 12 years of age.

In the context of dyslexia/motor impairment support for a common underlying neurological impairment comes from those studies that report higher rates of left-handedness and ambidexterity in children with dyslexia (Annett, Eglinton, & Smythe, 1996; Annett & Turner, 1974; Demarest, 1982). Deviant laterality profiles have also been observed in children with motor impairment, manifested by a higher incidence of crossed dominance, but not a higher incidence of left-handedness (Armitage & Larkin, 1993). As deviant laterality profiles are observed in both dyslexic and motor impaired children this might not only be a general characteristic of the syndrome, but it might also provide a useful lead into the search for answers to the question as to why some children experience problems related to both motor and language skills.

Olson et al. (1989) found that phonological coding in children with reading disabilities was substantially lower than in younger non-disabled children. This was taken as an indication of a developmental deficit in phonological coding rather than a

developmental lag *per se*. That this might be genetically determined was inferred from data on identical and fraternal twins, which suggested that phonological coding was highly heritable. What other evidence is available that might support the idea of neurological impairment underlying language/motor disorders whether these relate to speech or dyslexia?

1.6 Inter/Intra Hemispheric Lesion/Disconnection

In a number of the studies already referred to in this Chapter it has been shown that particular samples of motor and speech/reading impaired children experience quite severe problems in bimanual co-ordination (Fawcett & Nicoloson, 1995; Fawcett et al., 1996; Owen & McKinlay, 1997). Given that the distal finger movements of the right and left hand, respectively, are controlled via the contralateral hemisphere (Bogen, 1993) such co-ordination requires efficient transfer of information between the hemispheres via the corpus callosum (Jeeves, 1990; Kalat, 1995; Preilowski, 1972, 1990; Quinn & Geffen, 1986). This has been supported in a series of studies carried out by Sigmundsson et al. (Sigmundsson, 1999; Sigmundsson, Ingvaldsen, & Whiting, 1997a,b; Sigmundsson, Whiting, & Ingvaldsen, 1999), addressed to inter and intra-hemispheric problems in 7-8 year-old children with motor impairment diagnosed as having hand-eye co-ordination problems – speech/reading disorders not being an issue addressed at that time. They proposed that the problems exhibited by these sub-groups of children with motor impairment could be behavioural manifestations of neurological impairment interpreted within a framework of an intra-hemispheric lesion/disconnection affecting the transfer of information within the hemispheres or an interhemispheric disconnection.

Within the context of speech/motor impairment, Owen and McKinlay (1997) found that a group of 16 developmental speech and language disordered children⁶ (age range 4-7 years) had significantly greater problems in bimanual tasks such as threading beads and fastening buttons compared to their controls (matched on age, sex and non-verbal intelligence). Although these researchers did not apply neurological

⁶ They made up a complete cohort for this age group of those children considered to have the most severe “developmental speech and language disorders” in the Salford district (3300 births per annum). The nature of their language problems was not further described.

interpretations to their data, the nature of these tasks suggests a problem in the interhemispheric transfer of information. Whether this reflects a callosal problem *per se* or the indirect effect of a left or right intra-hemispheric lesion is open to question. As the left hemisphere, traditionally, is considered to be dominant for both motor and speech (Kimura, 1982; Kimura & Archibald, 1974), this could be a plausible interpretation. It is perhaps more surprising to the reader that a putative right hemispheric dysfunction is also being suggested as an alternative to problems in the callosum *per se*. Although the evidence is limited, findings by Powell and Bishop (1992) of a balancing deficit specific to the non-preferred (left) leg in children with speech impairments could be indicative of an involvement of the right hemisphere.

That callosal dysfunction might be an underlying pathogenic factor in children with developmental dysphasia and dyslexia is a position put forward by Njiokiktjien, Valk, and Ramaekers (1988). This proposition builds on the earlier finding of Badian and Wolff (1977) that dyslexic males (8-26 years of age) performed significantly worse with their left hand than controls in tapping to a metronome when the requirement was to alternate hands, but performed equally well when required to tap with the right and left hand separately. They argued, on the basis of evidence from patients with surgical commissurotomies, that the motor deficiency in synchronising left and right hands might be due to a disturbance in interhemispheric co-operation. More recently Moore et al. (1996) found that dyslexia, particularly phonological dyslexia, is associated with deficits in interhemispheric interactions mediated by the corpus callosum.

The notion of an intra-left hemispheric disconnection gains support from a PET scan study of five adults with developmental dyslexia of a phonological kind and their controls (Paulesu et al., 1996). For the dyslexics only a subset of the brain regions normally involved in phonological processing was activated: Broca's area during the rhyming task and the temporo-parietal cortex during a short-term memory task. In controls both these areas were activated simultaneously. They proposed that the defective phonological system of the dyslexic be due to weak connectivity between anterior and posterior language areas (i.e., an intrahemispheric problem).

Denckla (1985) who investigated performance of rapid repetitive and alternating movements in a group of 40 pure dyslexic children provides some support for an intra-right hemispheric disconnection. She found a tendency towards large right-left differences, that is a tendency for the left side, normally somewhat slower in

a right-preferring population, to be even more so in this population. However, Denckla attributed this, and other findings of large left-right differences, to a deficiency in the 'callosal system', arguing that this need not be due to a defect in the fibres of the callosum, but that callosal transmission might be impaired by lesion in the cells of origin of the callosal fibres in the cortex or in the cortical cells on which the callosal fibres synapse.

Dyslexia Timing Hypothesis

An attempt to be more specific about the nature of such putative inter/intra hemispheric problems comes from research on temporal variables in timing precision and serial ordering in bimanual co-ordination. Wolff (1993; Wolff, Cohen & Drake, 1984; Wolff, Michel & Ovrut, 1990; Wolff, Michel, Ovrut & Drake, 1990), argued that temporal problems underlay the apparent interhemispheric problems observed in many dyslexics. The gist of his argument was that it is not impaired motor co-ordination that causes reading retardation, but that there is probably a third factor of impaired temporal resolution that expresses itself outwardly in both the manual motor and language skill performance of dyslexic individuals.

In an extension of an earlier study (Badian & Wolff, 1977) Wolff and colleagues (Wolff et al., 1984) turned their attention to aspects of timing control for motor speech and explored the possible links between impaired motor co-ordination and reading retardation. Twenty reading retarded 12-13 year old male volunteers of above average intelligence were compared to normal controls on synchronous finger tapping (single hand 92 bpm, alternating hand 184 bpm, alternating hand, 92 bpm), asynchronous intermanual tapping, motor speech and rapid automatised naming. They found that both groups could perform the manual and motor speech tasks adequately when movement speed was scaled to a sufficiently slow rate but that both groups showed a breakdown in co-ordinated movements at fast entrainment rates. While the bimanual tapping tasks were correlated with the reproduction of single syllables (both groups), reading achievement and spelling and rapid naming (reading retarded group), unimanual tapping proficiency was not correlated with any outcome measure. They argued that the greater impairment on tasks of interlimb co-ordination (asynchronous tapping in particular), but not in unimanual performance, is consistent with the hypothesis that impaired motor performance and reading retardation are both related to a reduced efficiency of interhemispheric communication. Given that the retarded

readers had difficulty preventing the momentarily inactive or non-leading hand from moving in unison with the active, or leading hand, they argued that the presumed inefficiency of interhemispheric communications may be associated with a failure to transmit motor inhibitory rather than motor excitatory impulses. Such a failure, they suggest, would have a relatively greater disruptive effect on co-ordinated bimanual trials than unimanual or synchronous bimanual tapping. The retarded readers also showed speech articulation difficulties on tasks requiring a rapid switching back and forth across different articulation patterns. Given that motor speech does not involve interlimb co-ordination and probably does not depend on efficient interhemispheric co-operation, it was argued that deficits in the temporal organisation of motor inhibitory commands might account for some of the performance deficits in both domains of motor function.

Based on this and later studies (for a review see Wolff, 1993), Wolff put forward three possible hierarchical explanatory models: 1) information processing within the left hemisphere (i.e. Growing up with grossly intact but dysfunctional cerebral commissures might, for example, be associated with the adequate transmission of degraded information, as in the case of left or right hemisphere anomalies); 2) reduced efficiency of interhemispheric communication (i.e., a slow rate of information transfer for time-distributed functions that require precise temporal integration between the hemispheres); or 3) selective dysfunction of the cerebellar hemispheres (i.e., a failure to suppress redundant or conflicting information between the hemispheres). The latter model is in line with other studies which have focused particularly on cerebellar dysfunction and to which reference has been made under the heading *Fine Motor Skills* earlier in this Chapter.

However, he did not regard these models as sufficient in themselves. In fact, he pointed to their limitation in the light of the plasticity of the neuromotor system which allowed individuals with localised brain lesions or abnormal patterns of neurological development to frequently achieve the same intended goal by alternative pathways when the usual flow of information is blocked or dysfunctional. He drew attention to a different theoretical perspective for this purpose, namely Dynamic Systems Theory (Kelso, Holt, Rubin, & Kugler, 1981), which focuses on how new patterns of behavioural co-ordination are formed during development from antecedent conditions that do not exhibit such novel properties. Research within this theoretical framework (Kelso & Tuller, 1981; Kelso et al., 1981) has demonstrated that the

frequency at which tasks of bimanual co-ordination are performed is a critical variable or control parameter in spontaneous pattern formation. Given the paradigmatic changes to which this approach has given rise in the fields of motor learning and control, its extension to the kinds of problem being addressed in this Chapter is awaited with much anticipation.

1.7 Magnocellular Deficit

Another interesting link to temporal insufficiency in children with dyslexia (Galaburda & Livingstone, 1993; Stein, 1993) is the proposition that a magnocellular deficit might be the neural basis of problems in processing rapidly changing signals by the CNS. From their studies of contrast sensitivity and visual temporal resolution of normal and dyslexic adults Galaburda and Livingstone (1993) have drawn the conclusion that dyslexics are less sensitive to low-contrast, fast visual stimulation and that the characteristics of the abnormalities are suggestive of a defect in the transient, or magnocellular, subdivision of the visual pathway. In post mortem studies they also found significant anatomical differences in the lateral geniculate nuclei between dyslexic brains and controls, the magnocellular bodies being generally smaller and more variable in size and shape, while the parvocellular layers appeared similar in the two groups. In further extrapolation of this work they suggest that a deficit in rapid information processing may not be limited to the visual modality, but may affect the ability to discriminate rapid auditory transitions as well. This proposition was based on the evidence from studies which have shown that language and reading impaired children have difficulty in distinguishing both consonant-vowel phonemes and non-linguistic cues if they involve rapid (around 40 ms) auditory transitions (Tallal, 1980). Additionally, reading disabled children who show defects in rapid visual information processing, also do poorly on tests of phonological skills (Tallal, Stark, Kallman, & Mellits, 1981). To date studies on magnocellular deficits have only been performed in relation to dyslexia but, given the importance of visual perception in motor co-ordination, in particular hand-eye co-ordination tasks, this could be an interesting hypothesis also with relation to subgroups of motor and language impairments.

1.8 Vestibular Hypothesis

In the previous sections the main focus has been on fine motor problems, in particular related to bimanual co-ordination and temporal sequencing. Postural problems have also figured prominently in the literature (Fawcett & Nicolson, 1992; Nicolson & Fawcett, 1990). These need also to be explained. For example, Fawcett & Nicolson (1992) showed that the balance performance of 11-year old and 15-year old groups of dyslexic children was significantly impaired by the introduction of a secondary task while the balance of the control groups of children (matched for age and IQ) without language problems was unaffected, that is, the dyslexic children needed to invest more attention to maintain adequate balance. In a similar vein, Kohen-Raz (1981) has shown 'trainability' of static balance to be significantly associated with level of reading ability.

Given the growing body of evidence of a significant relation between poor balance and different kinds of language problems, such as SLI, reading ability and dyslexia, it is surprising that few attempts have been made to specify the nature of this link, i.e. to go from description to explanation, particularly with respect to underlying aetiology.

One exception was that of Levinson (1988) who concluded that both dyslexia and other typically associated problems, like learning disabilities, attention deficit disorders, poor balance and co-ordination, and speech problems are all due to a signal-scrambling disturbance of inner-ear (Cerebellar-Vestibular) functioning. He claimed to have found an inner-ear dysfunction that characterised over 96% of a large dyslexic sample (1973). He expressed concern that the differing patterns of cerebral functioning in dyslexics vs. normals observed by the use of active imaging and electrophysiological techniques should be misinterpreted as causal factors of dyslexia, rather than the result of dyslexia. He put forward the hypothesis that such observations might rather be due to poor input due to a dysfunction in the vestibular system (inner ear). In support of a vestibular explanation is his own research (1991) (based on 4 case studies, drawn from a sample of 100) showing that motion sickness medication may relieve many of the problems experienced by learning disordered and dyslexic children, such as reading, drawing, handwriting, ball-catching, balance and co-ordination.

Except for the studies mentioned above there appears to have been little interest in the vestibular theory in the literature. One reason may be the rather speculative nature of the theory and the limited evidence on which it was based. Not the least of the concerns is the credibility of a single explanation of a *potpourri* of learning disabilities that include dyslexia, motor impairment and attention deficit disorders. As different subgroups of children with impaired language have been shown to exhibit different patterns of performance in a range of motor tasks, it is more likely, as suggested by Bradford and Dodd (1994), that their different surface production errors reflect different underlying deficits.

1.9 Conclusion

In many instances motor and language impairments in children may be highly correlated. Direct or indirect explanations for this overlap have been proposed. An indirect explanation would invoke social constraints associated with one of these forms of impairment adversely affecting the other giving rise to a vicious circle of cause and effect. While this form of mediation is an interesting line to pursue, it begs the question as to what gave rise to the motor and/or language impairments in the first place.

Direct effects would attribute both forms of deficiency to a developmental lag or to abnormal neural development (which may or may not have genetic overtones). Interpretations of this kind would, however, have to be qualified when it is recognised that there is no easily definable group of language/motor impaired children but rather a number of subgroups for which the correlations observed may require different, or at least modified, causal interpretations. Even the sub-categories on which attention has been focused in this Chapter, namely, speech/motor impairment and dyslexia/motor impairment are probably too coarse to provide more than suggestions as to a common aetiology.

The fact that many speech-impaired children, particularly those with phonological deficits, develop dyslexia, can probably account for the findings of similar motor problems in dyslexic and speech impaired groups of children.

Clearly, there is some way to go before the neurological implications of motor and language impairments, where they occur together, can be teased out. What is

clear, however, is that there is no shortage of putative explanations for either of the phenomena. It is the considered opinion of the present authors that research directed towards those groups of children who exhibit both motor and language impairments will, in the long run, lead to new methodological approaches that will clarify the nature of the aetiology, particularly with respect to the question of the relative contributions of nature and nurture.

1.10 References

- American Psychiatric Association (1994). *Diagnostic and Statistical Manual of mental disorders* (4th ed.). Washington DC: Author.
- Annett, M., Eglinton, E., & Smythe, P. (1996). Types of dyslexia and the shift to dextrality. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, 37, 167-180.
- Annett, M. & Turner, A. (1974). Laterality and the growth of intellectual abilities. *British Journal of Educational Psychology*, 44, 37-46.
- Armitage, M. & Larkin, D. (1993). Laterality, motor asymmetry and clumsiness in children. *Human Movement Science*, 12, 155-177.
- Badian, N.A. & Wolff, P.H. (1977). Manual asymmetries of motor sequencing in reading disability. *Cortex*, 13, 343-349.
- Barnett, A. & Henderson, S.E. (1992). Some observations on the figure drawings of clumsy children. *British Journal of Educational Psychology*, 62, 341-355.
- Bishop, D.V.M. (1990). Handedness, clumsiness and developmental language disorders. *Neuropsychologia*, 28, 681-690.
- Bishop, D.V.M. & Edmundson, A. (1987). Specific language impairment as a maturational lag: Evidence from longitudinal data on language and motor development. *Developmental Medicine and Child Neurology*, 29, 442-459.
- Björngen, I.A., Undheim, J.O., Nordvik, K.A., & Romslo, I. (1987). Dyslexia and hormone deficiencies. *European Journal of Psychology of Education*, 2, 283-295.
- Bogen, J.E. (1993). The callosal syndromes. In K.M. Heilman & R. Valenstein (Eds.), *Clinical neuropsychology* (3rd ed., pp. 337-407). NY: Oxford University Press.
- Bradford, A. & Dodd, B. (1994). The motor planning abilities of phonologically

- disordered children. *European Journal of Disorders of Communication*, 29, 349-369.
- Bradford, A. & Dodd, B. (1996). Do all speech-disordered children have motor deficits. *Clinical Linguistics and Phonetics*, 10, 77-101.
- Brenner, M.W., Gillman, S., Zangwill, O.L., & Farrell, M. (1967). Visuo-motor disability in schoolchildren. *British Medical Journal*, 4, 259-262.
- Brinton, B., Fujiki, M., Spencer, J.C., & Robinson, L.A. (1997). The ability of children with specific language impairment to access and participate in an ongoing interaction. *Journal of Speech Hearing and Language Research*, 40, 1011-1025.
- Corballis, M.C. (1998). Cerebral asymmetry: motoring on. *Trends in Cognitive Sciences*, 2, 152-157.
- Deiber, M.P., Passingham, R.E., Cloebatch, J.G., Friston, K.J., Nixon, P.D., & Frackowiak, R.S.J. (1991). Cortical areas and the selection of movement: a study with positron emission tomography. *Experimental Brain Research*, 84, 393-402.
- Demarest, W.J. (1982). In M. Annett (1985). *Left, right, hand and brain: the right shift theory*. London: Erlbaum.
- Denckla, M.B. (1985). Motor co-ordination in dyslexic children: Theoretical and clinical implications. In F.H. Duffy and N. Geschwind (Eds.), *Dyslexia: a neuroscientific approach to clinical evaluation* (pp. 187-195). Boston: Little, Brown and Co.
- Denckla, M.B., Rudel, R.G., & Broman, M. (1980). The development of a spatial orientation skill in normal, learning-disabled, and neurologically impaired children. In D. Caplan (Ed.), *Biological studies on mental processes*. Cambridge, Mass.: MIT Press.
- Dewey, D. (1995). What is developmental dyspraxia? *Brain and Cognition*, 29, 254-274.
- Dewey, D. & Wall, K. (1997). Praxis and memory deficits in language-impaired children. *Developmental Neuropsychology*, 13, 4, 507-512.
- Dow, R.S. & Moruzzi, G. (1958). *The physiology and pathology of the cerebellum*. Minneapolis: University of Minnesota Press.
- Eccles, J.C., Ito, M., & Szentagothai, J. (1967). *The cerebellum as a neuronal machine*. New York: Springer-Verlag.

- Edwards, S., Ellams, J., & Thompson, J. (1976). Language and intelligence in dysphasia: are they related? *British Journal of Disorders of Communication*, *11*, 83-94.
- Fawcett, A.J. & Nicolson, R.I. (1992). Automatisation deficits in balance for dyslexic children. *Perceptual and Motor Skills*, *75*, 507-529.
- Fawcett, A.J. & Nicolson, R.I. (1995). Persistent deficits in motor skill of children with dyslexia. *Journal of Motor Behavior*, *27*, 235-240.
- Fawcett, A.J. & Nicolson, R.I. (1999). Performance of dyslexic children on cerebellar and cognitive tests. *Journal of Motor Behavior*, *31*, 68-78.
- Fawcett, A.J., Nicolson, R.I., & Dean, P. (1996). Impaired performance of children with dyslexia on a range of cerebellar tasks. *Annals of Dyslexia*, *46*, 259-283.
- Gaddes, W.H. (1985). *Learning disabilities and brain function. A neuropsychological approach* (2nd ed.). New York: Springer-Verlag.
- Geschwind, N & Galaburda, A.M. (1985). Cerebral lateralization. Biological mechanisms, associations, and pathology: I. A hypothesis and a program for research. *Archives of Neurology*, *42*, 428-459.
- Gjessing, H.J., Nygaard, H.D., & Solheim, R. (1988). Bergen-prosjektet. *Utviklingsforløp og læreproblemer hos elever i grunnskolen III. Studier av barn med dysleksi og andre lesevansker* (Studies of children with dyslexia and other reading disabilities). Bergen: Universitetsforlaget.
- Galaburda, A. & Livingstone, M. (1993). Evidence for a magnocellular defect in developmental dyslexia. In P. Tallal, M. Galaburda, R.R. Llinas, & C. von Euler (Eds.). *Temporal information processing in the nervous system. Special reference to dyslexia and dysphasia. Annals of the New York Academy of Sciences*, vol. 682. New York: New York Academy of Sciences.
- Gubbay, S.S. (1975). *The clumsy child. A study of developmental apraxic and agnosic ataxia*. London: W.B. Saunders.
- Gubbay, S.S. (1978). The management of developmental apraxia. *Developmental Medicine and Child Neurology*, *20*, 643-646.
- Harter, S. (1978). Effectance motivation reconsidered: Toward a developmental model. *Human Development*, *1*, 34-64.
- Henderson, S.E. (1977). Finding the clumsy child: genesis of a test of motor impairment. *Journal of Human Movement Studies*, *3*, 38-48.
- Henderson, S.E. & Hall, D. (1982). Concomitants of clumsiness in young

- schoolchildren. *Developmental Medicine and Child Neurology*, 24, 448-460.
- Henderson, S.E., May, D.S., & Umney, M. (1989). An exploratory study of goal-setting behaviour, self-concept and locus of control in children with movement difficulties. *European Journal of Special Needs Education*, 4, 1-15.
- Hewes, G.W. (1973). *Primate communication and the gestural origins of language*. *Current Anthropology*, 14, 5-24.
- Hill, E.L. (1998). A dyspraxic deficit in specific language impairment and developmental coordination disorder? Evidence from hand and arm movements. *Developmental Medicine and Child Neurology*, 40, 388-395.
- Hill, E.L., Bishop, D.V.M., & Nimmo-Smith, I. (1998). Representational gestures in developmental coordination disorder and specific language impairment: Error-types and the reliability of ratings. *Human Movement Science*, 17, 655-678.
- Holmes, G. (1917). The symptoms of acute cerebellar injuries due to gunshot injuries. *Brain*, 40, 461-535.
- Holmes, G. (1939). The cerebellum of man. *Brain*, 62, 1-30.
- Ivry, R. (1993). Cerebellar involvement in the explicit representation of temporal information. In P. Tallal, M. Galaburda, R.R. Llinas, & C. von Euler (Eds.). *Temporal information processing in the nervous system. Special reference to dyslexia and dysphasia*. *Annals of the New York Academy of Sciences*, vol. 682. New York: New York Academy of Sciences.
- Ivry, R. B. & Diener, H.C. (1991). Impaired velocity perception in patients with lesions of the cerebellum. *Journal of Cognitive Neuroscience*, 3, 355-366.
- Ivry, R.B. & Keele, S.W. (1989). Timing functions of the cerebellum. *Journal of Cognitive Neuroscience*, 1, 134-150.
- Jeeves, M.A. (1990). Agenesis of the corpus callosum. In R.D. Nebes & S. Corkin (Eds.). *Handbook of neuropsychology*. Amsterdam: Elsevier Science Publishers B.V.
- Kalat, J.W. (1995). *Biological psychology*. USA: Brooks/Cole Publishing Company.
- Kalliopuska, M. & Karila, I. (1987). Association of motor performance on cognitive, linguistic, and socioemotional factors. *Perceptual and Motor Skills*, 65, 399-405.
- Keele, S., Ivry, R., & Pokorný, D. (1987). Force control and its relation to timing. *Journal of Motor Behaviour*, 19, 96-114.
- Keele, S., Pokorný, R., Corcos, D., & Ivry, R. (1985). Do perception and motor

- production share common timing mechanisms? *Acta Psychologica*, 60, 173-193.
- Kelso, J.A.S. (1995). *Dynamic patterns: The self-organization of brain and behavior* (p.91). Cambridge, MA: The MIT Press.
- Kelso, J.A.S., Holt, K.G., Rubin, P., & Kugler, P.N. (1981). Patterns of interlimb coordination emerge from properties of non-linear, limit cycle oscillatory processes: Theory and data. *Journal of Motor Behaviour*, 13, 226-261.
- Kelso, J.A.S. & Tuller, B. (1981). Towards a theory of apractic syndromes. *Brain and Language*, 13, 224-245.
- Keogh, J.F., Sugden, D.A., Reynard, C.L., & Calkins, J.A. (1979). Identification of clumsy children: Comparisons and comments. *Journal of Human Movement Studies*, 5, 32-41.
- Kimura, D. (1982). Left-hemisphere control of oral and brachial movements and their relation to communication. *Philosophical Transactions of the Royal Society of London*, B298, 135-49.
- Kimura, D. & Archibald, Y. (1974). Motor functions of the left hemisphere. *Brain*, 97, 337-50.
- Kimura, D. (1993). Neuromotor mechanisms in human communication. Oxford psychology series no. 20. *New York, Oxford: Oxford university press*.
- Kohen-Raz, R. (1981). Postural control and learning disabilities. *Early Child Development and Care*, 7, 329-352.
- Lambe, E.K. (1999). Dyslexia, gender, and brain imaging. *Neuropsychologia*, 37, 521-536.
- Levinson, H.N. (1973). Dysmetric dyslexia and dyspraxia: hypothesis and study. *Journal of American Academy of Child Psychiatry*, 12, 690-701.
- Levinson, H.N. (1988). The cerebellar-vestibular basis of learning disabilities in children, adolescents and adults: hypothesis and study. *Perceptual and Motor Skills*, 67, 983-1006.
- Levinson, H.N. (1991). Dramatic favourable responses of children with learning disabilities or dyslexia and attention deficit disorder to antimotion sickness medications: four case reports. *Perceptual and Motor Skills*, 73, 723-738.
- Liberman, A. M. (1993). In speech perception, time is not what it seems. In P. Tallal, M. Galaburda, R.R. Llinas, & C. von Euler (Eds.). *Temporal information processing in the nervous system. Special reference to dyslexia and dysphasia*.

- Annals of the New York Academy of Sciences*, vol. 682. New York: New York Academy of Sciences.
- Liepmann, H. (1908). *Drei Aufsätze aus dem Apraxiegebiet*. Berlin: Karger Verlag.
(Translated by D. Kimura (1980) as *Translations from Liepmann's essays on apraxia*. University of Western Ontario, Department of Psychology Research Bulletin, No. 506.
- Losse, A., Henderson, S.E., Elliman, D., Hall, D., Knight, E., & Jongmans, M. (1991). Clumsiness in children - do they grow out of it - a 10-year follow-up-study. *Developmental Medicine and Child Neurology*, 33, 55-68.
- Mæland, A.F. (1992). Identification of children with motor co-ordination problems. In A.F. Mæland (Ed). *Learning disabilities and motor co-ordination problems in schoolchildren* (pp 42-58). Trondheim, Norway: Universitetet i Trondheim, Den Allmenvitenskapelige Høyskolen.
- Moore, L.H., Brown, W.S., Markee, T.E., Theberge, D.C., & Zvi, J.C. (1996). Callosal transfer of finger localisation information in phonologically dyslexic adults. *Cortex*, 32, 311-322.
- Nickisch, A. (1998). Motorische Störungen bei Kindern mit verzögerter Sprachentwicklung. *Folia Phoniatica*, 40, 147-152.
- Nicolson, R.I. & Fawcett, A.J. (1990). Automaticity: A new framework for dyslexia research? *Cognition*, 35, 159-82.
- Nicolson, R.I., Fawcett, A.J., Berry, E.L., Jenkins, I.H., Dean, P., & Brooks, D.J. (1999). Association of abnormal cerebellar activation with motor learning difficulties in dyslexic adults. *Lancet*, 353, 1662-1667.
- Njiokiktjien, C., Valk, J., & Ramaekers, G. (1988). Malfunction or damage to the corpus callosum? A clinical and MRI study. *Brain & Development*, 10, 92-99.
- Notherdaeme, M., Amorosa, H., Ploog, M., & Scheimann, G. (1988). Quantitative and qualitative aspects of associated movements in children with specific developmental speech and language disorders and in normal pre-school children. *Journal of Human Movement Studies*, 15, 151-169.
- O'Dwyer, S. (1987). Characteristics of highly and poorly co-ordinated children. *The Irish Journal of Psychology*, 8, 1-8.
- Olson, R., Wise, B., Conners, F., Rack, J., & Fulker, D. (1989). Specific deficits in component reading and language skills: genetic and environmental influences. *Journal of Learning Disabilities*, 22, 339-348.

- Orton, S.T. (1937). *Reading, writing, and speech problems in children: a presentation of certain types of disorders in the development of the language faculty*. New York: Norton.
- Owen, S.E. & McKinlay, I.A. (1997). Motor difficulties in children with developmental disorders of speech and language. *Child: Care, Health and Development*, 23, 315-325.
- Paul, R., Cohen, D.J., & Caparulo, B.K. (1983). A longitudinal study of patients with severe developmental disorders of language learning. *Journal of the American Academy of Child Psychiatry*, 22, 525-534.
- Paulesu, E., Frith, U., Snowling, M., Gallagher, A., Morton, J., Frackowiak, R.S.J., & Frith, C.D. (1996). Is developmental dyslexia a disconnection syndrome? Evidence from a PET scanning. *Brain*, 119, 143-157.
- Plaza, M. (1997). Phonological impairment in dyslexic children with and without early speech-language disorder. *European Journal of Disorders of Communication*, 32, 277-290.
- Powell, R.P. & Bishop, D.V.P. (1992). Clumsiness and perceptual problems in children with specific language impairment. *Developmental Medicine and Child Neurology*, 34, 755-765.
- Preilowski, B. (1972). Possible contribution of the anterior forebrain commissures to bilateral co-ordination. *Neuropsychologia*, 10, 267-77.
- Preilowski, B. (1990). Intermanual transfer, interaction, and handedness in man and monkeys. In Trevarthen, D. (Ed.). *Brain circuits and functions of the mind*. New York: Cambridge University Press.
- Preis, S., Bartke, S., Willers, R., & Müller, K. (1995). Motor skills in children with persistent specific grammatical language impairment. *Journal of Human Movement Studies*, 29, 133-148.
- Preis, S., Schittler, P., & Lenard, H.G. (1997). Motor performance and handedness in children with developmental language disorder. *Neuropediatrics*, 28, 324-327.
- Quinn, K. & Geffen, G. (1986). The development of tactile transfer of information. *Neuropsychologia*, 24, 793-804.
- Rintala, P., Pienimäki, K., Ahonen, T., Cantell, M., & Kooistra, L., (1998). The effects of a psychomotor training programme on motor skill development in children with developmental language disorders. *Human Movement Science*, 17, 721-737.

- Rizzolatti, G. & Arbib, A. (1998). Language within our grasp. *Trends in Neuroscience*, 21, 188-194.
- Roland, P.E., Larsen, B., Lassen, N.A., & Skinhoj, E. (1980). Supplementary motor area and other cortical areas in organization of voluntary movement in man. *Journal of Neurophysiology*, 43, 118-136.
- Rutter, M. (1978). Prevalence and types of dyslexia. In A.L. Benton and D. Pearl (Eds.), *Dyslexia. An appraisal of current knowledge*. New York: Oxford University Press.
- Rutter, M., Graham, P., & Yule, W. (1970). A neuropsychiatric study in childhood. *Clinics in Developmental Medicine*, (Nos. 35 and 36).
- Rutter, M. & Yule, W. (1975). The concept of reading retardation. *Journal of Child Psychology and Psychiatry*, 16, 181-197.
- Schlaug, G., Knorr, U., & Seitz, R.J. (1994). Inter-subject variability of cerebral activations in acquiring a motor skill - a study with positron emission tomography. *Experimental Brain Research*, 98, 523-534.
- Schoemaker, M. & Kalverboer, A.F. (1994). Social and affective problems of children who are clumsy: How early do they begin? *Adapted Physical Activity Quarterly*, 11, 130-140.
- Seitz, R.J., Schlaug, G., Knorr, U., Steinmetz, H., Tellmann, L., & Herzog, H. (1995). Neurophysiology of the human supplementary motor area: positron emission tomography. In: Leuders, H.O. (Ed.), *Advances of Neurology*, 70, 167-175.
- Shaw, L., Levine, M.D., & Belfer, M. (1982). Developmental double jeopardy: A study of clumsiness and self-esteem in children with learning problems. *Developmental and Behavioral Pediatrics*, 3, 191-196.
- Sigmundsson, H. (1999). Inter-modal matching and bi-manual co-ordination in children with hand-eye co-ordination problems. *Nordisk Fysioterapi*, 3, 55-64.
- Sigmundsson, H., Ingvaldsen, R.P., & Whiting, H.T.A., (1997a). Inter- and intra-sensory modality matching in children with hand-eye-co-ordination problems. *Experimental Brain Research*, 114, 492-499.
- Sigmundsson, H., Ingvaldsen, R.P., & Whiting, H.T.A., (1997b). Inter- and intra-sensory modality matching in children with hand-eye-co-ordination problems: exploring the developmental lag hypothesis. *Developmental Medicine and Child Neurology*, 12, 790-796.
- Sigmundsson, H., Whiting, H.T.A. & Ingvaldsen, R.P. (1999). 'Putting your foot in

- it! A window into clumsy behaviour. *Behavioural Brain Research*, 102, 131-138.
- Silva, P.A., McGee, R., & Williams, S. (1985). Some characteristics of 9-year-old boys with general reading backwardness or specific reading retardation. *Journal of Clinical Psychology and Psychiatry*, 26, 407-421.
- Stein, J.F. (1993). Dyslexia- impaired temporal information processing? In P. Tallal, M. Galaburda, R.R. Llinas, & C. von Euler (Eds.). *Temporal information processing in the nervous system. Special reference to dyslexia and dysphasia. Annals of the New York Academy of Sciences*, vol. 682. New York: New York Academy of Sciences.
- Stein, J.F. (1994). Developmental dyslexia, neural timing and hemispheric lateralization. *International Journal of Psychophysiology*, 18, 241-249.
- Stein, J.F. & Glickstein, M. (1992). Role of the cerebellum in visual guidance of movement. *Physiological Reviews*, 72, 967-1017.
- Stevenson, J. (1984). Predictive value of speech and language screening. *Developmental Medicine and Child Neurology*, 26, 528-538.
- Tallal, P. (1980). Auditory temporal perception, phonics, and reading disabilities in children. *Brain and Language*, 9, 182-198.
- Tallal, P., Curtiss, S., & Kaplan, R. (1988). The San Diego longitudinal study: Evaluating the outcomes of preschool impairment in language development. In S.E. Gerber & G.T. Mencher (Eds.). *International perspectives on communication disorders* (pp. 86-126). Washington, D.C.: Gallaudet University Press.
- Tallal, P., Stark, R., Kallman, C., & Mellits, D. (1981). A reexamination of some nonverbal perceptual abilities of language-impaired and normal children as a function of age and sensory modality. *Journal of Speech and Hearing Research*, 24, 351-357.
- Tamas, L.B., Schibasaki, T., Horikoshi, S., & Ohye, C. (1993). General activation of cerebral metabolism with speech: a PET study. *International Journal of Psychophysiology*, 14, 199-208.
- Van Rossum, J.H.A. & Vermeer, A. (1990). Perceived competence: A validation study in the field of motoric remedial teaching. *International Journal of Disability, Development and Education*, 37, 71-91.
- Wolf, M. (1980). The word retrieval process and reading in children and aphasics. In

- K. Nelson (Ed.), *Children's language* (Vol. 3). New York: Gardner.
- Wolff, P.H. (1993). Impaired temporal resolution in developmental dyslexia. In P. Tallal, M. Galaburda, R.R. Llinas, & C. von Euler (Eds.). *Temporal information processing in the nervous system. Special reference to dyslexia and dysphasia. Annals of the New York Academy of Sciences, vol. 682*. New York: New York Academy of Sciences.
- Wolff, P.H., Cohen, C. & Drake, C. (1984). Impaired motor timing control in specific reading retardation. *Neuropsychologia, 22*, 587-600.
- Wolff, P.H., Melngailis, I., Obregon, M., & Bedrosian, M. (1995). Family patterns of developmental dyslexia. 2. Behavioral phenotypes. *American Journal of Medical Genetics, 0060*, 494-505.
- Wolff, P.H., Michel, G.F., & Ovrut, M. (1990). The timing of syllable repetitions in developmental dyslexia. *Journal of Speech and Hearing Research, 33*, 281-289.
- Wolff, P.H., Michel, G.F., Ovrut, M., & Drake C. (1990). Rate and timing precision of motor coordination in developmental dyslexia. *Developmental Psychology, 26*, 349-359.
- World Health Organization (1980). *International classification of impairments, disabilities and handicaps - A manual of classification relating to the consequences of disease*. Geneva: Author.
- World Health Organization (1997). *International classification of impairments, activities and participation (ICIDH-2). A manual of dimensions of disablement and functioning*. Geneva: Author.

Chapter 2

WHY MIGHT LANGUAGE AND MOTOR IMPAIRMENTS OCCUR TOGETHER?

2.1 Abstract

A step-wise methodology is employed in order to identify common neurological factors underlying motor and language impairments where they occur together. A sample of 15 5-10-year-old children with predetermined language impairment was tested comprehensively using the Illinois Test of Psycholinguistic Ability (ITPA) and the Movement Assessment Battery for Children (Movement ABC). On the basis of these tests, only 4 of the sample were found to have generally poor performance both in psycholinguistic (particularly indexed by problems with visual closure and sound blending) and motor abilities (particularly indexed by manual dexterity problems - bimanual co-ordination and drawing - and static balance). Further detailed examination of the findings fostered a number of plausible hypotheses to account for this communality. The viability of these different alternatives is discussed.

Key words: motor impairment, language impairment, corpus callosum, right hemisphere, static balance, bimanual skills, visuospatial skills, and sound blending.

2.2 Introduction

While a link between motor impairment and language impairment would seem to be well accepted, given the frequency of its citation (Tallal & Stark, 1982; Cermak *et al.*, 1986; Sommers, 1988; Notherdaeme *et al.*, 1988; Bradford & Dodd, 1996; Owen & McKinlay, 1997; Hill, 1998; Hill, 2001), the reasons underlying the correlation are often obscure. Seldom has the nature of the link been teased out in order to determine which particular motor problems and which particular language problems occur together and, when they do so, what the common mediating factors are likely to be. Some interesting attempts at the former have, however, been made. Language impaired children have been shown to experience problems in relation to: speed of peg-moving (Owen & McKinlay, 1997; Bishop & Edmundson, 1987; Powell & Bishop, 1992), threading beads

and fastening buttons (Owen & McKinlay, 1997), making gestures using hand and arm movements (Hill, 1998); associated movements accompanying hand and finger movements e.g. hand-patting, hand pronation/supination, index-thumb opposition, sequential finger-opposition and diadochokinesis (Notherdaeme *et al*, 1988); balance, particularly retaining balance on the non-preferred foot (Powell & Bishop, 1992); and non-motor tasks such as visual discrimination (Powell & Bishop, 1992).

Given the heterogeneity of the language impairment groups, however, it would be legitimate to ask whether such problems are common to all such subjects or whether different kinds of problem are associated with particular sub categories of language impairment? Attempts to provide answers to such a question have seldom been pursued in any depth in the literature, primarily because of the diversity of dependent variables addressed, whether in the movement or language categories. Dodd, Leahy and Hambly (1989) in signalling this unfortunate omission point out that this makes it difficult to establish causal factors. Consequently, the effectiveness of remedial approaches based on such limited analyses will be less than optimal. In three language based experiments they investigated the possibility that the different surface language production errors made by three subgroups of phonologically language disordered children (delayed language, consistent deviant language and, inconsistent deviant language) reflected different underlying deficits. They report that the different patterns of performance of their groups of language impaired children, support the notion that subgroups of language impairment are relatively distinct and their different surface production errors reflect different underlying deficits. Such a categorisation, in principle, provides a sounder basis on which to design remedial procedures.

A different, but similarly motivated, approach was provided by Preis, Bartke, Willers and Müller (1995). They argue that a careful examination of motor skill performances in well-defined sub-groups of language impaired children may enable researchers to qualify more clearly the nature of the language impairment. Focusing on a subgroup of specific language impaired children with a grammatical type of impairment without severe phonological and semantic-pragmatic deficits, they found that even this group of children, without significant articulatory (motor) deficits, were impaired in the performance of complex fine motor skills. The group performed significantly poorer than a control group in total aiming-time (but not aiming-error), and speed of pegs moving (right hand). They suggested that both the motor and

language problems in these children might be explained by an underlying deficit in programming co-ordinated sequences. In a later study Preis, Schnittler & Lenard (1997) found a different group of language impaired children, with developmental language disorder (DLD) of a phonologic syntactic subtype, to have problems with finger tapping (both hands) and pegboard performance (both hands).

These studies clearly indicate the need for the nature of language impairments to be more clearly analysed and the resulting categorisations linked to different problems in motor skill performance. What is noticeable, however, is the comparable absence of neuropsychological hypotheses to account for these putative commonalities.

With this in mind, the present study was designed to make it possible to tease out potential relations between basic psycholinguistic and motor abilities and, if successful, to put forward plausible neuropsychological explanations. The departure point, in this respect, was to attempt to provide answers to two sets of questions:

- 1) To what extent is there a relation between poor psycholinguistic abilities (as measured by the Illinois Test of Psycholinguistic Abilities) and motor impairment (as measured by the Movement Assessment Battery for Children) in language impaired children?
- 2) What could be the common mediating factor(s)?

From the literature review presented it is predicted here that language impaired children will be poorer than children that are not language impaired in the performance of fine motor skills, like bimanual co-ordination, speed of manual movements, static balance, making gestures, and non-motor skills like visual discrimination.

With respect to the question of common mediating factors, a number of possible candidate neuropsychological explanations have been put forward in the literature and these will be returned to in the discussion. Sigmundsson and his colleagues (Sigmundsson, 1999; Sigmundsson *et al.*, 1997a, 1997b, 1999), for example, signal possible interhemispheric information transfer problems while other authors have focused on cerebellar mediation. In the latter context, Ivry and his colleagues (Ivry & Diener, 1991; Ivry & Keele, 1989; Keele, Ivry & Pokorny, 1987; Keele *et al.*, 1985) have suggested the possibility of a breakdown in the control of the temporal coupling of signals. This hypothesis is given credence by the work of Fawcett and Nicolson (1995, 1999; Fawcett, Nicolson, & Dean, 1996; Nicolson *et al.*, 1999) in their work with phonological dyslexics, a deficit that is closely related to phonological language impairment (Plaza, 1997). Using clinical tests of cerebellar function, they found

dyslexics to be impaired on balance and a number of fine motor asks associated with cerebellar function.

2.3 Methods

Participants

Two special education teachers (speech therapists) actively involved in the assessment of language disorders were asked to provide a sample of children with language impairment (LI) with whom they were working. The speech therapists defined LI as children with expressive oral language problems (both phonological and/or articulatory problems included), and they produced a list of N = 15 children (nine boys and six girls) between the ages of 5 and 10 years who fell into this category. Two participants were left-handed (preferred hand to write), and these were excluded, in order to avoid confounding related to handedness (i.e. potentially different cerebral organisation in left handers, as suggested by Waal, Sigmundsson & Whiting, 2000). A common trait in this group of children was the inability to produce correct language sounds. The children were considered normal in other aspects of development. These were the complete sample of the LI children being handled by these two speech therapists at that point in time. Many of the children had been followed up since the age of four and a few since the age of two because of their abnormal language development. Most of the participants were selected on the basis of the special teachers' knowledge and experience, using a combination of formal and informal testing procedures. The respective class teachers selected control subjects matched on age (\pm 6 months), sex, and socio-economic background with no known learning problems. The school aged children (7 years and older) in both groups were attending ordinary, i.e. non-selective, school classes in Norwegian primary schools, while the youngest children (those under 7 years) were in ordinary public kinder gardens.

Procedure

Assessment of psycholinguistic abilities. Both groups were required to complete the Illinois Test of Psycholinguistic Abilities (ITPA), under the guidance of a trained test administrator. The ITPA (Kirk *et al.*, 1968) is designed to measure 10 psycholinguistic functions in children by means of 12 sub-tests: Auditory Reception, Visual Reception,

Visual Sequential Memory, Auditory Association, Auditory Sequential Memory, Visual Association, Visual Closure, Verbal Expression, Grammatical Closure, Manual Expression, Auditory Closure, and Sound Blending. In addition to a global score, the test yields a profile of psycholinguistic abilities. ITPA is standardised in Norway (Gjessing *et al.*, 1975) for children from 4-10 years of age and is traditionally used for testing children with dyslexia and other language problems, children with visual and/or auditory problems, and mentally challenged persons. The mean standard score indicates the level of total communicative ability, a score of 36 representing the "normal" (average) population in each age group.

Out of the remaining 13 language impaired children 8 had an average score below the age-related norm of 36 (according to the Norwegian standardisation) in psycholinguistic performance. To ensure as homogeneous a group as possible, the five children whose scores were not significantly different from those of normal controls, together with their matched controls, were removed from the sample. This left a language impaired group of eight children (Table 1) who had a mean ITPA score more than 2 standard scores below average in psycholinguistic abilities (mean score 31.98. Range 30.50-33.30. SD 0.963) and a matched control group of eight participants (mean score 38.69. Range 36.00- 42.50. SD 2.00).

Table 1: Gender (F/M), chronological age (Age) and mean standard scores (12 sub-tests) on the ITPA for the language impaired (n = 8) and the control group (n = 8).

Language impaired group			Control group		
Participant	Age	ITPA	Participant	Age	ITPA
A (M)	5.07	33	I (M)	5.10	38
B (F)	7.01	32	J (F)	6.10	38
C (F)	7.01	33	K (F)	7.10*	38.5
D (M)	9.04	32	L (M)	8.10	42.5
E (M)	8.03	31	M (M)	8.09	37
F (F)	7.03	32	N (F)	7.05	39
G (F)	7.04	31	O (F)	7.05	36
H (F)	7.04	32	P (F)	7.10	40
Mean	7.40	31.98	Mean	7.72	38.69
S.D.	1.07	0.96	S.D.	1.17	2.00

* The teacher did not manage to find a control subject that was closer in age.

Note: Participants A, B, C, D are the same individuals in tables 1, 3 and 4.

Assessment of motor skills. For this purpose the Movement ABC (Henderson & Sugden, 1992) a formalised standardised test to identify children with motor impairment problems, was used. The test-battery provides both a quantitative and qualitative evaluation of children's motor competence. The test battery is divided into four age bands: 4-6 years, 7-8 years, 9-10 years and 11-12 years. Each age band contains eight sub-tests divided into three categories: three tests of manual dexterity (MD1, MD2 and MD3), two tests of ball skills (BS1 and BS2) and three tests of static (StB) and dynamic (DB1 and DB2) balance. On each sub-test the child receives a score from 0-5, 0 representing the best performance. These scores add up to a "total impairment score", in which a score of 0 would be equivalent to the 96th percentile (good motor performance), a score of 4 would place a child within the 54th percentile (average performance), 10 would place a child within the 15th percentile, classified as borderline motor impaired, while a child with a score below 13 would belong to the 5th percentile (motor impaired).

Data Analysis and Statistics

All statistical comparisons utilised the Wilcoxon Signed Ranks test for matched pairs, and were performed using the SPSS statistical package. One-tailed tests were used for those three Movement ABC sub-tests (MD1, MD2 and StB) as well as the Movement ABC Total score where, according to the literature review, the language impaired sample would be predicted to have significantly poorer performance than the normal sample. On the remaining five sub-tests, where no differences between the groups were to be expected, two-tailed tests were used. Probabilities below $\alpha = 0.05$ were regarded as significant.

2.4 Results

Quantitative analysis

The results of the total scores on the Movement ABC showed there to be a significant difference in overall motor performance between the two groups (Table 2).

However, the motor problems expressed by these language impaired children would not appear to be general, but rather restricted, significant differences between the groups being found only on bimanual co-ordination (MD2) ($p = 0.02$, one-tailed. Mean difference: 2.50; SD 2.14) and drawing (MD3) ($p = 0.04$, two-tailed. Mean difference:

1.38; SD 1.77) - both factors of manual dexterity (reflected also here by their intercorrelation - $\rho = 0.73$, $p = 0.00$, one-tailed) - and Static Balance ($p = 0.02$, one-tailed. Mean difference: 1.56; SD 1.57).

There was also a significant correlation between bimanual co-ordination (MD2) and Static Balance (StB) ($N = 16$, $\rho = 0.50$, $p = 0.05$, two-tailed), but not between drawing (MD3) and static balance (StB) ($\rho = 0.32$, $p = \text{n.s.}$, two-tailed). Significant differences between the groups, in favour of the control group, were found both in relation to right ($p = 0.01$, one-tailed. Mean difference: 1.38; SD 1.41) as well as left ($p = 0.01$, one-tailed. Mean difference: 2.38; SD 1.41) foot balance. What also stands out are the relatively large standard deviations on all sub-tests for the language impaired group suggesting that the group is anything but homogeneous with respect to motor performance. The correlation coefficient between the total standard score of the ITPA (all 12 sub-tests) and the total score of the Movement ABC (all 8 sub-tests included), both groups taken together, was also significant ($N = 16$, $\rho = -0.47$ one-tailed, $p < 0.05$).

At a global level, these results confirm the findings of those studies that have shown a significant association between language and motor impairment although, the common variance accounted for was only 20%. This, it might be argued, is low and is probably due to a relation that is confined only to certain members of the sample. Thus, further, more detailed probing, is required before a more clear-cut distinction in this respect can be made.

Qualitative analysis

Sub-categorisation of language impaired group in relation to motor impairment

In order to examine the generality of the language/motor impairment link, participants in the language impaired group were classified according to their percentile score on the Movement ABC. Two of the language impaired children were above average in motor performance (79th percentile), while the remaining six were below average: 32, 29, 13, 2, 0, and 0 percentiles respectively. Only those four participants that were below the 15th percentile were characterised as both language and motor impaired. It is clear, therefore, that the relation between motor and psycholinguistic abilities is not as direct as one might at first have been led to believe. To probe this relation further it is necessary to explore in more detail the nature both of the psycholinguistic weaknesses and the motor problems experienced by these participants, i.e. to discover if it is possible to identify

common psycholinguistic and/or motor problems, or whether each child represents a special case?

Table 2: Means and standard deviations (S.D.) for the language impaired group and control group, together with means, standard deviations, and p-values (p) for the differences between the groups on the 8 sub-tests of the Movement ABC: Manual Dexterity 1 (MD1), Manual Dexterity 2 (MD2), Manual dexterity 3 (MD3), Ball Skills 1 (BS1), Ball Skills 2 (BS2), Static Balance (StB), Dynamic Balance 1 (DB1), Dynamic Balance 2 (DB2), and the total score (SUM).

	Language impaired group (n = 8)		Control group (n = 8)		Differences between groups		
	Mean	S.D.	Mean	S.D.	Mean	S.D.	p
MD1	1.56	1.78	0.56	1.12	1.00	1.85	n.s *
MD2	2.88	2.03	0.38	0.74	2.50	2.14	0.02 *
MD3	1.50	1.77	0.13	0.35	1.38	1.77	0.04 **
BS1	1.38	2.00	0.81	1.42	0.56	2.32	n.s **
BS2	1.75	2.05	0.38	0.52	1.38	2.14	n.s **
StB	1.75	1.44	0.19	0.53	1.56	1.57	0.02 *
DB1	0.63	1.77	0.00	0.00	0.71	1.89	n.s **
DB2	1.25	2.31	0.00	0.00	1.25	2.31	n.s **
SUM	12.44	10.48	2.44	2.58	10.00	9.88	0.01 *

* Wilcoxon Signed Ranks test for matched pairs, one-tailed.

** Wilcoxon Signed Ranks test for matched pairs, two-tailed.

Search for common problems in language and motor impairment

Psycholinguistic profile. It can be seen (Table 3) that on almost every sub-test of the ITPA one or more of the participants has difficulty, confirming the diversity of the psycholinguistic problems. The results of the two sub-tests Visual Closure (VC) and Sound Blending (SB) may be distinguished, all four participants scoring more than one SD below the mean on these two sub-tests. On the other hand the only sub-test in which none of the participants deviate significantly from the control group is Visual Reception.

Table 3: Scores on the ITPA - profile - Auditory Reception (AR), Visual Reception (VR), Visual Memory (VM), Auditory Assosiation (AA), Auditory Memory (AM), Visual Association (VA), Visual Closure (VC), Verbal Expression (VE), Grammatical Closure (GC), Manual Expression (ME), Auditory Closure (AC), Sound Blending (SB) - of the 4 participants (A, B, C, D) that are weak in both motor and language performance. Scores that are one standard deviation (= 32) or more below the mean are marked with bold numbers.

ITPA - sub-tests	A	B	C	D
AR	39	29	27	35
VR	33	37	38	34
VM	32	30	33	36
AA	29	32	35	28
AM	35	24	24	33
VA	27	40	36	30
VC	30	23	31	32
VE	33	34	30	35
GC	33	28	31	29
ME	40	39	48	29
AC	33	31	28	39
SB	30	24	28	30
Mean	33	32	33	32

Note: Participants A, B, C, D are the same individuals in tables 1, 3 and 4.

Motor Profile. It has now been established that four language impaired participants share two commonalties in their linguistic profile, poor Sound Blending and poor Visual Closure. What also stands out is that the link to the Movement ABC is in relation to the sub-tests bimanual co-ordination (MD2), drawing (MD3) and static balance (StB). Bimanual co-ordination for the 5-year-olds involves threading wooden beads onto a lace, for 7-year-olds it involves threading a lace through a wooden lacing board and, for the 9-year-olds, threading nuts onto a bolt with the one hand while holding the bolt in the other. In the drawing task the child was required to track the lines of a flower trail (or, for the 5-year olds, a bicycle trail) on a sheet of paper with a pen. Static balance involves balancing on one leg with the free leg bent backward for the 5-year olds. The 7-year olds have to balance on one leg with the sole of the other foot against the side of the supporting knee, while the requirement for the 9-year olds is to balance on one leg on top of a wooden board. All age groups have to perform the task with the preferred leg first and then the non-preferred leg.

As the bimanual co-ordination, drawing and Static Balance tests of the Movement ABC were shown to discriminate between this particular group of language impaired children and their controls, these sub-tests were returned to. The individual scores on these sub-tests are shown in Table 4. For the purpose of identifying putative neurological problems, the Static Balance scores of the right and left leg are separated.

Table 4: Overview of the scores (percentile equivalents in parentheses) of the four language/motor impaired participants on the sub-tests of the Movement ABC - Static Balance (StB) and Bimanual Co-ordination (MD2).

ABC-sub-tests	A		B		C		D	
MD2	5	(2)	5	(2)	3	(10)	4	(5)
MD3	3	(10)	5	(2)	0	(100)	1	(25)
StB combined	1.5	(25)	1.5	(25)	4	(5)	2	(15)
StB right leg	0	(100)	1	(25)	4	(5)	1	(25)
StB left leg	3	(10)	2	(15)	4	(5)	3	(10)

Note: Participants A, B, C, D are the same individuals in tables 1, 3 and 4.

A sub-test's maximum score is 5.

On Static Balance both legs combined, one (D) of the participants was within the 15th percentile, and one (C) fell within the 5th percentile. However, when each leg was measured separately (all four children were right leg preferrent) all of the participants scored within or below the 15th percentile using the left leg, while only one (C) scored within or below the 15th percentile using the right leg. The table also shows that all four participants scored below the 15th percentile on bimanual co-ordination (MD2), three (A, B, D) being below the 5th percentile, indicating that this is a common problem. In the drawing (tracking) task only two out of the four children (A and B) really experienced problems, one (A) corresponding to the 10th percentile while the other (B) to the 2nd. The third subject (C) was below normal, scoring at the 25th percentile, while the fourth subject (D) had a normal score at the 100th percentile.

Now, several features seem to be distinguished in these four participants with poor psycholinguistic and motor abilities, namely poor performance on: static balance (left leg being particularly affected) and bimanual co-ordination sub-tests of the movement ABC, and Visual Closure and Sound Blending sub-tests of the ITPA.

2.5 Discussion

This study set out to explore, in a step-wise manner, potentially subtle relations between language and motor impairments in a sample (N = 15) of 5-10 year old children with predetermined language impairment. The departure point was the proposal that there is a significant relation between poor psycholinguistic abilities and poor motor abilities, and that this relation may not be fortuitous. It was expected that the investigation of this relation would lead to the generation of new hypotheses concerning putative underlying factors.

Quantitative analysis

At a global level, the finding of a significant correlation between motor impairment and poor psycholinguistic skills in this group of children reflects very much the findings of many other studies (Preis *et al.*, 1995, 1997; Mæland & Søvik, 1995; Merriman *et al.*, 1995; Robinson, 1987). More specifically, the finding that the motor problems of the language-impaired children were restricted to distal movements (fine manual movements) and static balance raises some interesting issues. In the first place, these particular motor abilities are generally considered to represent different factors of general motor ability (Fleishman 1964). Why, then, should such apparently disparate factors, in this sub-sample of language and motor-impaired children be affected? At a neuropsychological level, two candidate explanations seem worthy of further exploration:

1. The cerebellar deficit hypothesis
2. The inter-hemispheric deficit hypothesis

Cerebellar deficit hypothesis

This hypothesis arises from the work of Fawcett, Nicolson and colleagues (Fawcett & Nicolson 1995, 1999; Fawcett *et al.*, 1996; Nicolson *et al.*, 1999). The dyslexic samples in their studies demonstrated impairment on clinical tests of cerebellar function. Some of these cerebellar tests involved speed of manual movement, bimanual co-ordination and static balance i.e., similar categories of motor skill as appeared to be critical to language and motor impairment in the present study. Why should bimanual co-ordination be linked to cerebellar problems? According to Ivry and colleagues (Ivry & Diener, 1991; Ivry & Keele, 1989; Keele *et al.*, 1987; Keele *et al.*, 1985), bimanual movements may be

dependent on the temporal coupling of signals within the cerebellum. Each half of the cerebellum has been shown to regulate the temporal aspects of movements on the ipsilateral side independently. This suggestion is based on findings from repetitive finger tapping tests on cerebellar patients.

The significant differences between the groups on the task of drawing (tracking) can also be accommodated in the cerebellar explanation. A study using positron emission tomography (PET) (Jueptner *et al.*, 1996) showed that the cerebellum, and to some extent the basal ganglia, were activated during a visually guided tracking task, where the participants had to track a series of lines with a mouse pointer on the screen. Also, in a study of cerebral blood flow Grafton *et al.* (1992) found that tracking a moving target with the index finger activated the primary motor cortex, dorsal parietal cortex, precuneate cortex, supplementary motor area and ipsilateral anterior cerebellum.

That language/motor impaired children exhibit similar deficiencies in motor skills to those of dyslexic persons suggests that there might be a common mechanism that mediates all these deficiencies. Diamond (2000), in a more recent study, probes deeper into the causal network in her concept of a neuroanatomical circuit deficiency between the prefrontal cortex and the cerebellum. She argues that motor and cognitive development are much more interrelated than has been previously appreciated, pointing to the fact that fine motor control, bimanual co-ordination, and visuomotor skills, together with certain cognitive operations, are not fully developed until adolescence. This, she argues, may be seen in relation to the phylogenetic development of the neocerebellum and prefrontal cortex, which proceed in parallel.

Inter/intra hemispheric deficit

The observed problems in bimanual co-ordination replicate the earlier finding of Owen and McKinlay (1997) that language impaired children will experience problems in bimanual tasks such as threading beads and fastening buttons. As discussed above, a number of authors have focused on cerebellar dysfunction in this context, and interpreted their findings in the light of the cerebellar timing hypothesis (Ivry & Diener, 1991; Ivry & Keele, 1989; Keele *et al.*, 1987; Keele *et al.*, 1985). However, given the fact that temporally dependent bimanual co-ordination problems have been observed in co-occurrence with bimanual co-ordination tasks that are independent of temporal constraints (Sigmundsson, 1999; Sigmundsson *et al.*, 1997a, 1997b, 1999), the cerebellar

timing hypothesis would not seem to hold for all kinds of bimanual co-ordination. The same kind of bimanual co-ordination problems (screwing nuts onto bolts and threading beads) to those observed in the present study, have been found in a group of 8-year-old motor impaired children with particular problems in hand-eye co-ordination (Sigmundsson, 1999). These difficulties were complemented by problems in the transfer of proprioceptive information from right to left hand (when vision was excluded) in intra-modal matching tasks, and were attributed, tentatively, to inter-hemispheric transfer problems (Sigmundsson, 1999; Sigmundsson *et al.*, 1997a, 1997b, 1999). Could a similar interpretation have relevance for the field of language impairment and hence for the communality in the language and motor impairments? A useful hypothesis for future experimentation might, therefore, be that children with similar language/motor impairment as the group in the present study have a general problem in the transference of information from one hemisphere to the other.

That static balance problems may be caused by a cerebellar deficit has already been discussed. However, the most striking finding in the present sample was the poor performance on the left leg in the static balance test. This is in line with Powell and Bishop's finding (Powell & Bishop, 1992), and is not likely to be an effect of the children being more trained on the right foot, because the standardised test used provides norms for the right as well as the left leg. Sigmundsson, Whiting and Ingvaldsen (1999) found similar left-right differences albeit on a foot-hand-matching task, in motor impaired children (in whom, possible language problems were not in question). They found that children with hand-eye co-ordination problems performed significantly poorer than the normal group in a condition where presumably only the right hemisphere was involved⁷ (left foot location/left hand matching), and in the conditions where information had to be transported across the corpus callosum (left foot location/right hand matching and right foot location/left hand matching). They interpreted this finding as a putative right hemisphere insufficiency with or without a dysfunctional corpus callosum. As static balance on one leg involves proprioceptive information from the foot, such information from the left leg being processed in the right hemisphere (Sperry, 1974), it

⁷ The issue whether distal movements are controlled only by the contra lateral hemisphere in humans (rather than just monkeys) remains controversial. For example an MRI functional study (Kim *et al.*, 1993) and a study of regional cerebral blood flow (Roland *et al.*, 1982) have shown ipsi lateral involvement in distal motor control.

may be speculated whether the balancing problems in the present group of children could have a similar interpretation.

Qualitative inspection

Of the selected group of eight language impaired children only three were classified as motor impaired at the fifth percentile criterion level and one other borderline (below the 15th percentile). This indicates that only about 50 % of language impaired children are affected by motor impairments as well, and that such explanations as those suggested above may only apply to a subgroup of the sample as a whole. The qualitative inspection of the participants in the motor/language impaired subgroup revealed that it is only on two of the sub-tests that all four participants are considerably below the norm, i.e. perform within or below the 15th percentile. These are bimanual co-ordination and static balance on the left leg. In addition to the problems with bimanual co-ordination and left leg balancing (sub-tests of the Movement ABC) discussed above, this subgroup was indexed particularly by problems in Visual Closure and Sound Blending (sub-tests of the ITPA).

The sub-test Visual Closure requires the subject to find how many dogs are hidden in a black-white drawing (Paraskevopoulos & Kirk, 1969) and depends on the ability to recognise the whole from parts. This ability is also necessary in the Gollin picture test with which patients with right hemispheric lesions are shown to experience problems (Warrington, 1985). This suggests the possibility of a right hemispheric involvement.

The task of Sound Blending involves sequential assignment of letters to sounds, followed by blending (e.g. CAT → 'cuh-ah'tuh' →), and is commonly regarded as the ITPA sub-test most sensitive to identifying phonological dyslexia. Phonological dyslexia is shown to go hand-in-hand with bimanual co-ordination problems that, in turn, are associated with deficits in inter hemispheric interactions mediated by the corpus callosum (Moore *et al.*, 1996).

2.6 Conclusion

The conclusions that follow have to be seen in the light of the relatively small group of the larger sample in this study shown to exhibit both language and motor impairments:

1. Coincidence of language and motor impairments is characteristic of only a limited sample of language impaired children. Caution should, therefore, be observed in making generalisations on the basis of group data, without a more careful investigation of individual language/motor profiles.
2. Where motor and language impairments occur together, the motor deficiencies may not be general but restricted to a relatively small number of fine motor skills.
3. Both the cerebellar deficit and inter/intra hemispheric deficit hypotheses would appear to provide plausible neuropsychological explanations for the co-occurrence of language and motor impairments. It remains for future studies to examine the viability of both explanations using larger and, perhaps, more diverse samples of children belonging to different age groups.

2.7 References

- Bishop, D.V.M. & Edmundson, A. (1987). Specific language impairment as a maturational lag: Evidence from longitudinal data on language and motor development. *Developmental Medicine and Child Neurology*, 29, 442-459.
- Bradford, A. & Dodd, B. (1996). Do all speech-disordered children have motor deficits? *Clinical Linguistics and Phonetics*, 10, 77-101.
- Cermak, S.A., Ward, E.A., & Ward, L.M. (1986). The relationship between articulation disorders and motor co-ordination in children. *American Journal of Occupational Therapy*, 40, 546-550.
- Diamond, A. (2000). Close interrelation of motor development and cognitive development and of the cerebellum and prefrontal cortex. *Child Development*, 71, 44-56.
- Dodd, B., Leahy, J., & Hambly, G. (1989). Phonological disorders in children: underlying cognitive deficits. *British Journal of Developmental Psychology* 7, 55-71.

- Fawcett, A.J. & Nicolson, R.I. (1995). Persistent deficits in motor skill of children with dyslexia. *Journal of Motor Behavior*, 27, 235-240.
- Fawcett, A.J. & Nicolson, R.I. (1999). Performance of dyslexic children on cerebellar and cognitive tests. *Journal of Motor Behavior* 31, 68-78.
- Fawcett, A.J., Nicolson, R.I., & Dean, P. (1996). Impaired performance of children with dyslexia on a range of cerebellar tasks. *Annals of Dyslexia*, 46, 259-283.
- Fleishman, E.A. (1964). *The structure and measurement of physical fitness*. New Jersey: Prentice-Hall.
- Gjessing, H.J., Nygaard, H.D., & Solheim, R. (1975). *ITPA: Illinois test of psycholinguistic abilities: en orientering om den norske utgaven av ITPA*. Bergen: forfatterne.
- Grafton, S.T., Mazziotta, J.C., Woods, R.P., & Phelps, M.E. (1992). Human functional anatomy of visually guided finger movements. *Brain*, 115, 565-587.
- Henderson, S. & Sugden, D. (1992). *The movement assessment battery for children*. Kent: The Psychological Corporation.
- Hill, E.L. (1998). A dyspraxic deficit in specific language impairment and developmental co-ordination disorder? Evidence from hand and arm movements. *Developmental Medicine and Child Neurology*, 40, 388-395.
- Hill, E.L. (2001). Non-specific nature of specific language impairment: a review of the literature with regard to concomitant motor impairments. *International Journal of Language & Communication Disorders* 36, 149-171.
- Ivry, R.B. & Diener, H.C. (1991). Impaired velocity perception in patients with lesions of the cerebellum. *Journal of Cognitive Neuroscience*, 3, 355-366.
- Ivry, R.B. & Keele, S.W. (1989). Timing functions of the cerebellum. *Journal of Cognitive Neuroscience*, 1, 134-150.
- Jueptner, M., Jenkins, I.H., Brooks, D.J., Frackowiak, R.S.J., & Passingham, R.E. (1996). The sensory guidance of movement: A comparison of the cerebellum and basal ganglia. *Experimental Brain Research*, 112, 462-474.
- Keele, S., Ivry, R., & Pokorny, D. (1987). Force control and its relation to timing. *Journal of Motor Behaviour*, 19, 96-114.
- Keele, S., Pokorny, R., Corcos, D., & Ivry, R. (1985). Do perception and motor production share common timing mechanisms? *Acta Psychologica*, 60, 173-193.
- Kim, S.G., Ashe, J., Hendrich, K., Ellerman, J.M., Merkle, H., Ugurbil, K., &

- Georgopoulos, A.P. (1993). Functional magnetic-resonance-imaging of motor cortex – hemispheric-asymmetry and handedness. *Science*, *261*, 615-617.
- Kirk, S.A., McCarthy, J.J., & Kirk, W.D. (1968). *The Illinois Test of Psycholinguistic Abilities*. Rev. ed. Urbana: University of Illinois Press.
- Mæland, A.F. & Søvik, N. (1995). *Children with motor co-ordination problems and learning disabilities in reading, spelling, writing and arithmetic*. Doctor Polit Thesis. Trondheim: University of Trondheim.
- Merriman, W.J., Barnett, B.E., & Isenberg, D. (1995). A preliminary investigation of the relationship between language and gross motor skills in preschool children. *Perceptual Motor Skills* *81*, 1211-1216.
- Moore, L.H., Brown, W.S., Markee, T.E., Theberge, D.C., & Zvi, J.C. (1996). Callosal transfer of finger localisation information in phonologically dyslexic adults. *Cortex* *32*, 311-322.
- Nicolson, R.I., Fawcett, A.J., Berry, E.L., Jenkins, I.H., Dean, P., & Brooks, D.J. (1999). Association of abnormal cerebellar activation with motor learning difficulties in dyslexic adults. *Lancet*, *353*, 1662-1667.
- Notherdaeme, M., Amorosa, H., Ploog, M., & Scheimann, G. (1988). Quantitative and qualitative aspects of associated movements in children with specific developmental speech and language disorders and in normal pre-school children. *Journal of Human Movement Studies* *15*, 151-169.
- Owen, S.E. & McKinlay, I.A. (1997). Motor difficulties in children with developmental disorders of speech and language. *Child: Care, Health and Development* *23*, 315-325.
- Paraskevopoulos, J. & Kirk, S.A. (1969). *The development and psychometric characteristics of the revised Illinois Test of Psycholinguistic Abilities*. Urbana: University of Illinois Press.
- Plaza, M. (1997). Phonological impairment in dyslexic children with and without early speech-language disorder. *European Journal of Disorders of Communication* *32*, 277-290.
- Powell, R.P. & Bishop, D.V.P. (1992). Clumsiness and perceptual problems in children with specific language impairment. *Developmental Medicine and Child Neurology* *34*, 755-765.
- Preis, S., Bartke, S., Willers, R., & Müller, K. (1995). Motor skills in children with persistent specific grammatical language impairment. *Journal of Human*

- Movement Studies*, 29, 133-148.
- Preis, S., Schnittler, P., & Lenard, H.G. (1997). Motor performance and handedness in children with developmental language disorder. *Neuropediatrics*, 28, 324-327.
- Robinson, R.J. (1987). *The causes of language disorder: introduction and overview*. In Proceedings of the First International Symposium of Specific Speech and Language Disorders in Children. Reading, London, England: AFASiC.
- Roland, P.E., Meyer, E., Shibasaki, T., Yamamoto, Y.L., & Thompson, C.J. (1982). Regional cerebral blood flow changes in cortex and basal ganglia during voluntary movements in normal human volunteers. *Journal of neurophysiology*, 48, 467-480.
- Sigmundsson, H. (1999). Inter-modal matching and bi-manual co-ordination in children with hand-eye co-ordination problems. *Nordisk Fysioterapi*, 3, 55-64.
- Sigmundsson, H., Ingvaldsen, R.P., & Whiting, H.T.A. (1997a). Inter- and intra-sensory modality matching in children with hand-eye-co-ordination problems. *Experimental Brain Research*, 114, 492-499.
- Sigmundsson, H., Ingvaldsen, R.P., & Whiting, H.T.A. (1997b). Inter- and intra-sensory modality matching in children with hand-eye-co-ordination problems: exploring the developmental lag hypothesis. *Developmental Medicine and Child Neurology*, 12, 790-796.
- Sigmundsson, H., Whiting, H.T.A., & Ingvaldsen, R.P. (1999). 'Putting your foot in it!' A window into clumsy behaviour. *Behavioural Brain Research*, 102, 129-136.
- Sommers, R.K. (1988). Prediction of fine motor skills of children having language and speech disorders. *Perceptual and Motor Skills*, 67, 63-72.
- Sperry, R.W. (1974). Lateral specialisation in surgically separated hemispheres. In F.O. Schmitt and F.G. Worden (eds.), *The Neurosciences: Third Study Program* (pp 5-19) Cambridge: The MIT Press.
- Tallal, P. & Stark, R.E. (1982). Perceptual/motor profiles of reading impaired children with or without concomitant oral language deficits. *Annals-of-Dyslexia*, 32, 163-176.
- Waal, A., Sigmundsson, H., & Whiting, H.T.A. (2000). Differential contributions of the two hemispheres in intra-modal proprioceptive sensory matching in 7-10-year-old boys. *Behavioural Brain Research*, 114, 17-22.
- Warrington, E.K. (1985). Agnosia: The Impairment of Object Recognition. In P.J.

Vinkin, G.W. Bruyn, and H.L. Klawans (Eds.) *Handbook of Clinical Neurology*. New York: Elsevier Science.

Chapter 3

THE VALIDITY OF THE INTER- AND/OR INTRA- HEMISPHERIC DEFICIT HYPOTHESIS AS AN EXPLANATION OF THE CO-OCCURRENCE OF MOTOR AND LANGUAGE IMPAIRMENTS

3.1 Abstract

From an initial cohort of 15 children between the ages of 5 and 10 years, who had expressive oral language problems, 4 were shown in an earlier study to be both motor and language impaired. Two explanatory hypotheses were proposed to account for this communality: a) cerebellar deficit, b) inter and/or intra hemispheric deficit. In order to explore the validity of the latter explanation, the same group of children, together with a matched control group, were required to carry out two sensory matching tests designed to tap inter- and intrahemispheric information processing abilities: hand-hand and foot-hand. The results, discussed in the light of Liederman's shielding model, provided more support for the hypothesis of an interhemispheric information-processing problem from left to right rather than an intrahemispheric problem.

Key words: Static balance, Bimanual skills, Visuospatial skills, Sound blending, Human.

3.2 Introduction

Support for a significant relation between language and motor skill performance has been provided by a number of studies (Tallal & Stark, 1982; Cermak *et al.*, 1986; Sommers, 1988; Notherdaeme *et al.*, 1988; Bradford & Dodd, 1996; Owen & McKinlay, 1997; Hill, 1998; Hill, 2001). The nature of this relation has, however, seldom been pursued in depth in the literature. Is the relation causal (i.e., does poor motor development influence the development of language or vice versa)? Or, is the putative relation an artefact of "critical neurological variables" underlying both motor and language impairment?

One recent attempt to pursue this issue was that of Estil, Whiting, Sigmundsson and Ingvaldsen (2003) who, after an investigation of the psycholinguistic and motor

profiles of a cohort of fifteen children between the ages of 5 and 10 years with expressive oral language problems, found that four of the children demonstrated common problems in sound blending, visual closure, bimanual co-ordination and static balance i.e., they exhibited both motor and language problems, the nature of which gave cause for concern. The cerebellar deficit (Fawcett & Nicolson 1995, 1999; Fawcett *et al.*, 1996; Nicolson *et al.*, 1999) and inter- and/or intrahemispheric deficit (Sigmundsson, 1999; Sigmundsson *et al.*, 1997a, 1997b, 1999) hypotheses were suggested as plausible neuropsychological explanations for the co-occurrence of these language and motor impairments. The study to be reported focuses on the validity of the inter- and/or intra hemispheric deficit hypothesis as an explanation of this communality.

The link, in this respect, is the series of studies carried out by Sigmundsson *et al.* (Sigmundsson, Ingvaldsen and Whiting, 1997a,b; Sigmundsson, Whiting and Ingvaldsen, 1999; Sigmundsson, 1999) on inter- and intra-hemispheric problems in children diagnosed as having hand-eye co-ordination problems - language disorders, at that time, not being an issue addressed. They proposed that the problems experienced by groups of 8 year old motor-impaired children diagnosed as having particular hand-eye co-ordination problems could be behavioural manifestations of putative neurological disorders interpreted within a framework of intra-hemispheric lesion and/or disconnection or inter-hemispheric disconnection. In order to examine the validity of Sigmundsson *et al.*'s hypothesis in the wider context of language *and* motor impairments, their tests were applied to the four children from the earlier study (Estil *et al.*, 2003) who had been shown to exhibit both motor and language impairments.

3.3 Method

Subjects

Subjects for this study were four children from an original cohort of 15 children between the ages of 5 and 10 years, with expressive oral language problems, shown by Estil *et al.* (2003) to be both motor and language impaired, together with four matched controls.

Procedure

The children were tested using two protocols:

- i) *interhemispheric matching* (hand/hand test and foot/hand test)
- ii) *intrahemispheric matching* (foot/hand test)

For the hand-hand test a tabletop apparatus (Sigmundsson et al., 1997a,b) was used, which required the subject to match the position of the index finger of the one hand with that of the other (interhemispheric matching). The foot-hand test utilised a small Perspex table-top (Sigmundsson et al., 1999) to match the position of the big toe (foot/hand test) on the one foot with the hand on the same side (intrahemispheric matching) or the opposite side (interhemispheric matching) of the body. In both the hand/hand test and the foot/hand test four trials were required for every condition. See Results section for more detailed procedural protocols for the testing.

Interhemispheric Matching (hand-hand test). This test comprised six different conditions, indexed by the perceptual system(s) used to locate (with one hand) the target on top of the apparatus table: Proprioception left hand (PL), Proprioception right hand (PR), Vision and proprioception left hand (VPL), Vision and proprioception right hand (VPR), Vision left hand (VL), Vision right hand (VR). Attempts to match the position of the located target (on the underside) with the other hand were all carried out without visual feedback.

Intrahemispheric matching (foot-hand test). Four different conditions were used in the experiment, defined by the perceptual system(s) used to locate (with the big toe) the target on the underside of the apparatus table: (Right foot location and left hand matching (RfLh), Left foot location and left hand matching (LfLh), Left foot location and right hand matching (LfRh), Right foot location and right hand matching (RfRh)). Attempts to match the position of the located target (on top of the apparatus table) with the hand were all carried out without visual feedback.

3.4 Results

Interhemispheric matching (hand-hand test)

Individual scores of the four language and motor impaired children. The 5 year-old (A), and 9 year-old (D) subjects were compared to the norms provided by

Sigmundsson et al. (1997), while the two 7-year old subjects (B and C) were compared to a group of 4 7-year old normal subjects. The results (Table 1) indicate that 3 (A, B and C) out of the 4 subjects performed more than 1SD below the norm in the PL condition. Notably, these 3 subjects were also the most severely motor impaired, scoring lower than the 5th percentile on motor performance as measured by the Movement assessment battery for children (ABC; Henderson & Sugden, 1992) while the fourth subject (D) was at the 13th percentile. While all 4 subjects showed problems in one or more of the conditions where proprioception (VPR, VPL, PR, PL) was involved, only one subject (A) showed problems in a "vision only" condition.

Table 1: Matching scores (distance in mm of pin from target) more than 1SD above the mean for each of the four language-/motor impaired subjects in each of the 6 conditions - Proprioception Left hand (PL), Proprioception Right hand (PR), Vision and Proprioception Left hand (VPL), Vision and Proprioception Right hand (VPR), Vision Left hand (VL), Vision Right hand (VR).

	A (5 years)	B (7 years)	C (7 years)	D (9 years)
VR	21.25*	17.25	10.75	9.50
VL	19.75	20.5	14.75	15.00
VPR	15.75	30.25*	13.25	12.75
VPL	20.50	33.00*	14.50	26.25*
PR	31.00	43.00*	28.25	28.00
PL	59.00*	33.25*	41.75*	25.25

* Individual scores that are more than 1SD above the mean.

It is also interesting to note that one of the subjects (B) performed poorly on all conditions in which proprioception was involved.

Group differences. The two groups were equally distributed with respect to gender (two boys and two girls in each group) and age (language and motor impaired: mean age 7.27 years; SD 1.55 vs. normal group: mean age: 7.35 years; SD 1.30). The mean scores of the four trials at each condition were computed for each subject. The mean scores of the language and motor impaired group (n = 4) were compared to those of the normal group (n = 4) using the Mann Whitney U test, one-tailed. Significant differences ($p < 0.05$) between the groups were found for the PL condition only, the language and motor impaired group having both a larger mean (39.81) and larger standard deviation (14.46) than the normal group (mean 23.25; SD 2.15) on this

variable. For the other two conditions that required matching with the left hand (VL and VPL) the differences between the groups just failed to reach the $p=.05$ criterion ($p = 0.057$). In the VL condition the language and motor impaired group had a mean of 17.50 (SD 3.05) while the normal group had a mean of 13.81 (SD 1.92). The means and standard deviations for both groups were higher in the VPL condition: language and motor impaired (mean 23.56; SD 7.91) versus normal group (mean 16.06; SD 3.07).

Intrahemispheric matching (foot-hand test)

Individual scores of each of the four language and motor impaired subjects.
The 5 year-old (A) and 9 year-old (D) subjects were compared to the norms (in randomly selected groups of children) provided by Sigmundsson, Whiting and Loftesnes (2000) as well as their respective controls, while the two 7-year old subjects (B and C) were compared to the norms provided by Sigmundsson, Ingvaldsen and Whiting (1999) as well as their respective controls. In Table 2 the individual scores that are 1SD or more above the mean are presented.

Table 2: Mean matching scores (distance in mm of pin from target) for each of the four language-/motor-weak subjects in each of the 4 conditions: Right foot location and left hand matching (RfLh); Left foot location and left hand matching (LfLh); Left foot location and Right hand matching (LfRh); Right foot location and right hand matching (RfRh).

	A (5years)	B (7years)	C (7years)	D (9 years)
RfLh	40.25	46.75*	80.00*	34.75
LfLh	34.75	29.50	89.75*	57.25*
LfRh	43.50	46.25	69.00*	13.25
RfRh	45.75	42.00	81.00*	18.50

* Individual scores that are more than 1SD above the mean.

Table 2 shows that one of the subjects (C) experienced problems in all conditions while two of the subjects (A and D) did not show any signs of inferior performance, although the performance of subject D in the LfLh condition was almost 1SD above that of the control subject (mean: 45.25; SD 13.60). Subject B showed inferior performance in the RfLh condition only.

Difference between groups. The same statistical procedures were used as for the hand/hand matching. The language and motor-impaired group as a whole was shown to be inferior to the normal group in all conditions, however none of the differences between the groups reached significance.

3.5 Discussion

The results from the present group of language and motor impaired children differed from the motor impaired children in the study by Sigmundsson et al. (1999) on the task that required intra-hemispheric processing. While both groups in the study by Sigmundsson et al (1999) performed better in the intra- rather than the interhemispheric condition, no such pattern could be found in any of the groups in the present study. Instead, the language and motor-impaired group showed a different pattern from that of the control group, although both groups had their worst performance in the condition requiring intra-right hemispheric processing (LrLh). Further, Sigmundsson et al.'s (1999) finding of a left foot-left hand matching problem was not characteristic of the children in the present study, as no significant differences were found on this variable (except in one of the subjects). Thus, the hypothesis that their language and motor problems may be due to an intra-right or intra-left hemispheric deficit could not be confirmed.

However, the present language and motor impaired subgroup exhibited similar right left differences as the samples with hand-eye co-ordination problems in the studies by Sigmundsson et al. (1997a, 1997b), supporting the hypothesis that interhemispheric transfer of proprioceptive information from left to right is more problematic than from right to left.

An attempt to explain such asymmetry was provided by Liederman (1986). According to Liederman's shielding model, the corpus callosum may (in these children) fail to actively shield, or minimise, interhemispheric interactions between the two hemispheres when the children are required to carry out simultaneous, but independent processing, for example when the child is required to do a different movement with the opposite hand or foot (localising with one limb and matching with the other). Because the inhibitory neurons of the corpus callosum fail, there is interference between the hemispheres and the non-dominant hemisphere fails when

required to perform a different task than the dominant hemisphere. This may also explain why samples of language impaired children are shown to have more associated movements in an attempt to perform gestures with one hand (Notherdaeme et al, 1988) and why very young children, who still have an immature corpus callosum, run into difficulties in their attempts to perform different movements with their right and left hand respectively. A failure of the inhibitory neurones of the corpus callosum may cause phonological as well as visual problems when auditory or visual stimuli from the right and left auditory or visual field are competing.

Thus, the indices of a possible right hemispheric dysfunction (left foot balancing problems and the Visual Closure) in the present study may be explained in a similar vein. As no significant differences on the task requiring intra-right hemispheric information processing (Lflh) was found the shielding theory would seem more likely than an intra-right hemispheric explanation.

3.6 References

- Bradford, A. & Dodd, B. (1996). Do all speech-disordered children have motor deficits? *Clinical Linguistics and Phonetics*, 10, 77-101.
- Cermak, S.A., Ward, E.A., & Ward, L.M. (1986). The relationship between articulation disorders and motor co-ordination in children. *American Journal of Occupational Therapy*, 40, 546-550.
- Estil, L.B., Whiting, H.T.A., Sigmundsson, H., & Ingvaldsen, R.P. (2003). Why might language and motor impairments occur together. *Infant and Child Development*. Accepted.
- Fawcett, A.J. & Nicolson, R.I. (1995). Persistent deficits in motor skill of children with dyslexia. *Journal of Motor Behavior*, 27, 235-240.
- Fawcett, A.J. & Nicolson, R.I. (1999). Performance of dyslexic children on cerebellar and cognitive tests. *Journal of Motor Behavior*, 31, 68-78.
- Fawcett, A.J., Nicolson, R.I., & Dean, P. (1996). Impaired performance of children with dyslexia on a range of cerebellar tasks. *Annals of Dyslexia*, 46, 259-283.
- Henderson, S., & Sugden, D. (1992). *The movement assessment battery for children*. Kent: The Psychological Corporation.
- Hill, E.L. (1998). A dyspraxic deficit in specific language impairment and

- developmental co-ordination disorder? Evidence from hand and arm movements. *Developmental Medicine and Child Neurology*, 40, 388-395.
- Hill, E.L. (2001). Non-specific nature of specific language impairment: a review of the literature with regard to concomitant motor impairments. *International Journal of Language and Communication Disorders*, 36, 149-171.
- Liederman, J. (1986). Subtraction in addition to addition: Dual task performances improves when tasks are presented to separate hemispheres. *Journal of Clinical and Experimental Neuropsychology*, 8, 486-502.
- Nicolson, R.I., Fawcett, A.J., Berry, E.L., Jenkins, I.H., Dean, P., & Brooks, D.J. (1999). Association of abnormal cerebellar activation with motor learning difficulties in dyslexic adults. *Lancet*, 353, 1662-1667.
- Notherdaeme, M., Amorosa, H., Ploog, M., & Scheimann, G. (1988). Quantitative and qualitative aspects of associated movements in children with specific developmental speech and language disorders and in normal pre-school children. *Journal of Human Movement Studies*, 15, 151-169.
- Owen, S.E. & McKinlay, I.A. (1997). Motor difficulties in children with developmental disorders of speech and language. *Child: Care, Health and Development*, 23, 315-125.
- Sigmundsson, H. (1999). Inter-modal matching and bi-manual co-ordination in children with hand-eye co-ordination problems. *Nordisk Fysioterapi*, 3, 55-64.
- Sigmundsson, H., Ingvaldsen, R.P., & Whiting, H.T.A. (1997a). Inter- and intra-sensory modality matching in children with hand-eye-co-ordination problems. *Experimental Brain Research*, 114, 492-499.
- Sigmundsson, H., Ingvaldsen, R.P., & Whiting, H.T.A. (1997b). Inter- and intra-sensory modality matching in children with hand-eye-co-ordination problems: exploring the developmental lag hypothesis. *Developmental Medicine and Child Neurology*, 12, 790-796.
- Sigmundsson, H., Whiting, H.T.A., & Ingvaldsen, R.P. (1999). 'Putting your foot in it!' A window into clumsy behaviour. *Behavioural Brain Research*, 102, 129-136.
- Sigmundsson, H., Whiting, H.T.A., & Loftesnes, J.M. (2000). Development of proprioceptive sensitivity. *Experimental Brain Research*, 135, 348-352.
- Sommers, R.K. (1988). Prediction of fine motor skills of children having language and speech disorders. *Perceptual and Motor Skills*, 67, 63-72.

Tallal, P., & Stark, R.E. (1982). Perceptual/motor profiles of reading impaired children with or without concomitant oral language deficits. *Annals-of-Dyslexia*, 32, 163-176.

Chapter 4

SPATIAL AND TEMPORAL CONSTRAINTS ON PERFORMANCE IN CHILDREN WITH MOVEMENT CO- ORDINATION PROBLEMS

4.1 Abstract

Eight, 10-year old children manifesting movement co-ordination problems (MCP), as assessed by the Movement Assessment Battery for Children (MABC), and a matched control group of eight children of a similar age without such problems, were required to carry out a laboratory ball-catching task. The task was constrained in such a way as to allow separate kinematic analyses of reaching (Experiment 1) and grasping (Experiment 2) subactions. Significant differences between the groups, in favour of the control group, were found with respect to both spatial and temporal performance in intercepting the moving ball. The MCP children were shown to have longer response times to moving targets and to initiate movement of the fingers earlier in time than the controls. MCP children also made more spatial errors. These findings are discussed in the context of the distinction made in the neuropsychological literature between proximal and distal motor control systems and the visual perceptual system.

Key Words: Hand-eye co-ordination; development; reaching; grasping; neural systems

4.2 Introduction

What characterises the movement behaviour of children classified as clumsy, is a failure to establish adequate movement co-ordination patterns with the rider that no evidence of CNS disorder is apparent (Gubbay 1975; Henderson & Hall 1982; Wall 1982; Mæland 1992). This is a syndrome that the American Psychiatric Association (1987) has labelled Developmental Co-ordination Disorder (DCD). To adopt this rider, however, is to take a very conservative standpoint - a standpoint that may need to be revised as knowledge in the field of neuroscience continues to become elaborated. For example, in a series of studies on children with hand-eye co-ordination problems (Sigmundsson, Ingvaldsen & Whiting 1997a,b; Sigmundsson, Whiting & Ingvaldsen 1999a,b) putative neurological disorders (inter- and/or intra-hemispheric processing problems) were invoked to account for the co-ordination

problems demonstrated. It is at this neural/behavioural interface that progress is likely to be made in going from description to explanation of movement disorders of this kind.

From a behavioural perspective, a variety of ways of assessing motor co-ordination problems have been devised - their limitations being pointed out by Sugden and Sugden (1990). The essential problem is that while one is able to signal the broad area(s) of motor behaviour in which such children demonstrate levels well below the norm it is not possible to pinpoint, with any degree of precision, the nature of the deficiency.

By way of illustration, consider the rather obvious ability of eye-hand co-ordination – an ability that is assessed in most general tests of motor performance. This ability alone embraces a wide range of possible movement behaviours dependent upon what is moving - the person, the target or both. Each of these categories of action can, in turn, be resolved into qualitatively different movement subactions. The act of catching a ball, for example, involves reaching to the position where the approaching ball will arrive and to perform a grasping action at the right time. In principle, when a catch is unsuccessful, the problem could reside in either, or both, of these component actions, as well as in the integration of the components into an efficient overall action.

With these constraints in mind, the research to be reported here focuses on just one action category, namely, eye-hand co-ordination when an object is moving and the person interacting is stationary (sitting). The task chosen is that of catching a ball, a task with severe temporal and spatial constraints and one with which all children are confronted at an early age. Alderson, Sully and Sully (1974) have signalled the severity of the constraints. Their analyses of the act of catching a tennis ball travelling with a speed of 10 ms^{-1} , albeit with adult subjects, showed the spatial constraints to be reflected in both gross and fine orientation. A gross spatial orientation of the catching hand took place some 200 ms prior to the catch, followed by a fine orientation some 50 ms later. The temporal adjustment, which involves the grasp and hold subactions, begins some 32-50 ms before the completion of the catching action and is constrained by a time window of $\pm 35 \text{ ms}$.

This kind of analysis can, of course, be pursued in more depth by asking, for example, what is it that leads to poor spatial and temporal conformity in a task like catching? This shifts the emphasis away from the outcome (spatial or temporal

conformity) to the kinematics of the movements initiated and carried out in the performance of the catching action. With respect to reaching and grasping, the transport and grasp subactions have to be finely attuned if performance is to be optimal. In the neurological literature, it has been proposed that these two subactions depend upon output information from different cortical regions - the posterior parietal and the inferior temporal, respectively (Jeannerod 1981, 1984; Jeannerod, Arbib, Rizzolatti & Sakata 1995). Jeannerod's (1994) contention is that reaching and grasping correspond to two different visuomotor channels. One deals with extrinsic properties of objects (their location in space with respect to the body, their velocity of motion, etc.) its function being to transport the hand to a desired location within extrapersonal action space. The other channel deals with intrinsic properties (like shape or size) its function being to shape the hand with the purpose of manipulating, identifying or transforming objects. Goodale and Milner (1992), on the other hand, claim that the ventral stream (projections from the primary visual cortex to the inferotemporal cortex) that is involved in identifying the approaching object (perception) operate independent from the dorsal stream (projections from the primary visual cortex to posterior parietal cortex) that control hand shaping (action). Thus, the degree to which the reaching and grasping actions are operated by independent visuomotor channels remain unclear. However, whether the channels are truly separated or linked, the subactions must be co-ordinated in time and space.

In summary, what is being presented here is a framework within which to explore one sub-category of the field of movement co-ordination, namely, eye-hand co-ordination using ball catching as a paradigm example. What makes this task particularly interesting is that, in everyday catching behaviour, spatial and temporal control are inextricably confounded. The hand has to be in the right place at the right time! In order to reduce the level of confounding and make it possible to tease out the locus of the problem, the methodology developed below has been designed in such a way as to minimise either the temporal or spatial constraints. The spatial constraints are emphasised by focusing on the reach to catch without the requirement to actually grasp the ball - proximal control (Experiment 1). The temporal constraints are emphasised by having the ball move on an invariant trajectory (Experiment 2) prior to it being caught by the hand (distal control), the forearm being constrained in order to reduce considerably the need for proximal control.

On the basis of empirical work on catching with ‘normal’ subjects (Savelsbergh, Whiting & Bootsma 1991; Savelsbergh, Whiting, Burden & Bartlett 1992; Savelsbergh, Whiting, Pijpers & Santvoord 1993) and on spatial interception in children with perceptuo-motor dysfunction (Bairstow & Laszlo 1989) and in the light of Alderson et al.’s (1974) analyses, the following hypothesis are made. In line with the results from the Bairstow and Laszlo study (1989) children with motor co-ordination problems will have longer response times to moving targets i.e. a delay in initiating both their proximal actions to intercept and their distal actions to open the hand and, subsequently, to grasp the ball. This, it is proposed, is because of planning uncertainty. Due to spatial uncertainty and limited proximal control (Jeannerod, 1986) they will be less accurate in spatially intercepting the target (ball). Their inability to match the severe temporal constraints (Alderson, Sully & Sully 1974) will cause high variability in the grasping action. Finally, they will show more preparatory movements (i.e. not strictly required for carrying out the task) in both the reaching and grasping phase due to spatial uncertainty about the position of the target and its time of arrival.

4.3 Experiment 1: Spatial uncertainty in the interception of a moving object

4.4 Methods

Subjects

All the 10- to 11- year old children from a city school in Norway (N=54) were tested on the Movement Assessment Battery for children (MABC) (Henderson & Sugden, 1992). Eight of the children, four males and four females, recorded scores below the 5th percentile (mean percentile 2.13; S.D. = 1.64) and were consequently categorised as having motor co-ordination problems (MCP). They constituted the experimental group. A sex- matched control group, without motor problems, of eight children who scored at or above the 65th percentile was also selected (mean percentile 89.38; S.D. = 8.37). To ensure that no motor problems were present in the control group, the 8 children with the best scores on the MABC were selected. The mean age of the MCP group was 10.97 years (S.D. = 0.32) while that of the control group was 10.86 years (S.D. = 0.38). All the 16 children selected were right handed.

Apparatus

A 'Plexiglas' screen measuring 1.21m long by 0.83m high was attached to the front edge of a table, behind which subjects sat in order to locate an approaching ball. The subject held a round disc, 5 cm in diameter in his or her hand (equivalent in diameter to that of the ball). In the middle of the disc a reflective marker was placed. The subject sat on a chair which could be adjusted in height, for both seat and foot rest position, leaving an angle of 90 degrees at both knee and elbow when the underarm was resting on the surface of the table. A cross within a circle marked the centre of the screen. This was at a right angle in front of the subject's head, about at the height of the nose. The cross marked the starting point for the subject's movements. Outside this, an area within which the subject could easily reach (the workspace), was marked. This was the area into which the ball to be located could be tossed by the experimenter.

A reflex taped rubber ball, 5 cm in diameter, was tossed overarm at the screen from a distance of 2.5m by an experimenter wearing dark sunglasses in order to prevent eyecontact that could provide visual cues to the subject. The mean horizontal velocity of the ball in flight was 4.21 m/s with a standard deviation of 0.21 m/s. There were no considerable differences in ball speed between the groups. The mean horizontal velocity of the balls ($n = 48$) thrown to the children in the MCP group was 4.21 m/s (S.D. = 0.24m/s) compared to 4.19m/s (S.D. = 0.20) for the balls ($n = 48$) thrown to those in the control group. The difference between the groups was not significant (T-test for independent samples, two tailed). The balls were thrown so as to hit the screen with an equal spatial distribution over the workspace (upper-right, upper-centre, upper-left, lower right, lower centre and lower-left) in a random order. To ensure conformity, the mean distance between the centre of the screen and the collision point for the sequence of throws was computed. For the 48 analysed trials (6 trials per person) of each group the mean movement distance (from the centre of the screen to the point where the ball hit the screen) was 317 millimetres (S.D. = 80.01) for the MCP group and 319.9 millimetres (S.D. = 76.18) for the control group. A two tailed t-test for independent samples revealed there to be no significant differences between the means of these distances for the two groups of subjects, i.e. the total movement distance required (the sum of the distances between the starting position of

the disc and the point at which the ball hit the screen) was approximately the same for the two groups.

Also, there was no significant difference in ball flight times (means and S.D.) between the groups. The mean ball flight time for the MCP group ($n = 48$ trials) was 462.80 ms (S.D. = 30.72) and that of the control group ($n = 48$ trials) was 458.10 ms (S.D. = 22.76).

Testing procedure

The subject, seated on the chair (adjusted to give the most comfortable position within the constraint requirements) behind the screen was informed that a ball was going to be tossed towards the screen. He or she was instructed as to how to hold the disc, how to move it in a ballistic action while maintaining contact with the surface starting the movement from the central, baseline, position. The subject was told to intercept the ball as it hit the screen and then to stop the movement.

All the children were instructed, both verbally and visually, by manually guiding them through the movements before the first trial. Each child performed 10 trials in succession. This limit was used in order to avoid too much influence of a potential learning effect. The first three trials were used as practice trials. During the practice trials instructions and corrections were made. This was necessary to make sure that the children understood the procedures. Trials 4-9 were to be used for statistical analyses. To ensure enough data, in case one of the trials 4-9 failed, the 10th trial was performed. However, it became necessary to include the 10th trial in the statistical analyses only in one occasion, because one of the reflexive markers fell off. The entire testing procedure lasted about 15 min for each child.

Data analyses and statistics

The three dimensional position (x , y , and z) of the markers were recorded by five ProReflex cameras (model MCU 240) using a sampling frequency of 200 Hz. The cameras were positioned at a height of 2 m above the floor and connected to a host computer (Gateway 2000) with Qtrac software for sampling of kinematic data. Prior to each sampling session the cameras were calibrated using the calibration procedure supplied by the manufacturer. The accuracy of the velocity measures was ± 0.015 m/s and for the position measures ± 0.14 mm.

All statistics were performed using the SPSS statistical package. The means and standard deviations for the dependent variables were computed for each subject. All comparisons between the groups utilised the T-Test for independent samples

Dependent variables

Two sets of dependent variable measures were used - one based on *temporal* measures, in ms relative to ball-screen contact (Figure 1) and the other based on *distance*, in millimetres, between the disc and the ball-screen collision point.

Time of Movement Initiation (TMI): The time at which the first movement of the disc away from the starting position occurred after the ball was tossed. This was defined as the point in time at which the acceleration in the x and/or y dimension started to increase above 2 standard deviations of mean (0) baseline value and remained positive more than 100 ms (Figure 2). The variable TMI was measured in ms prior to the time of ball-screen contact (obtained from the Pro-reflex recordings) as well as in ms after the time of ballrelease.

Time of Stopping (TS): The time at which the children stopped the movement of the disc as the ball hit the screen. TS was identified as the first point in time when the acceleration returned to baseline (0) and stayed within 2 standard deviations of the mean baseline for more than 100 ms (Figure 2).

Both the Distance of disc from ball-screen collision point at the moment of Collision (DC) and the Distance of disc from ball-screen collision point at time of Stopping the movement (DS) were measured. The distance between the disc and the collision point (the point at which the tossed ball hit the screen) was computed using the x and y co-ordinates for the position of the disc and the x and y co-ordinates of the ball-screen collision point, respectively, from the Pro-reflex recordings. At time of collision the x and y values of the disc were subtracted from those of the ball. The distance (d), in millimetres, was computed using the Pythagorean rule: $d^2 = (x^{\text{disc}} - x^{\text{ball}})^2 + (y^{\text{disc}} - y^{\text{ball}})^2$. Distance was measured in millimetres.

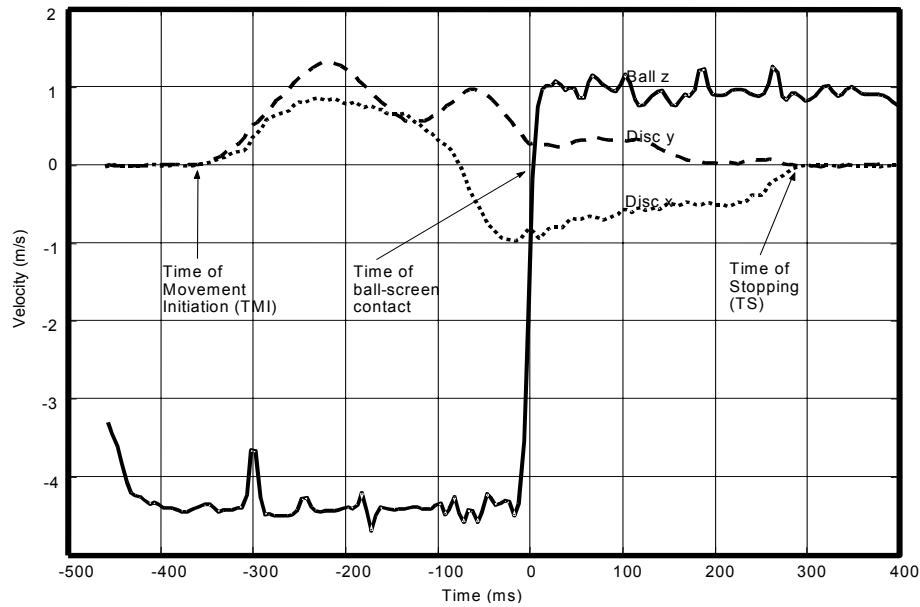


Figure 1: Velocity plots of the x (sideways) and y (upwards) dimensions of the disc movement as well as the z dimension (from thrower to screen) of the ball movement. Time of ball-screen contact as well as the variables Time of Movement Initiation (TMI) and Time of Stopping (TS) are marked. The time scale is in milliseconds relative to ball-screen contact (= 0).

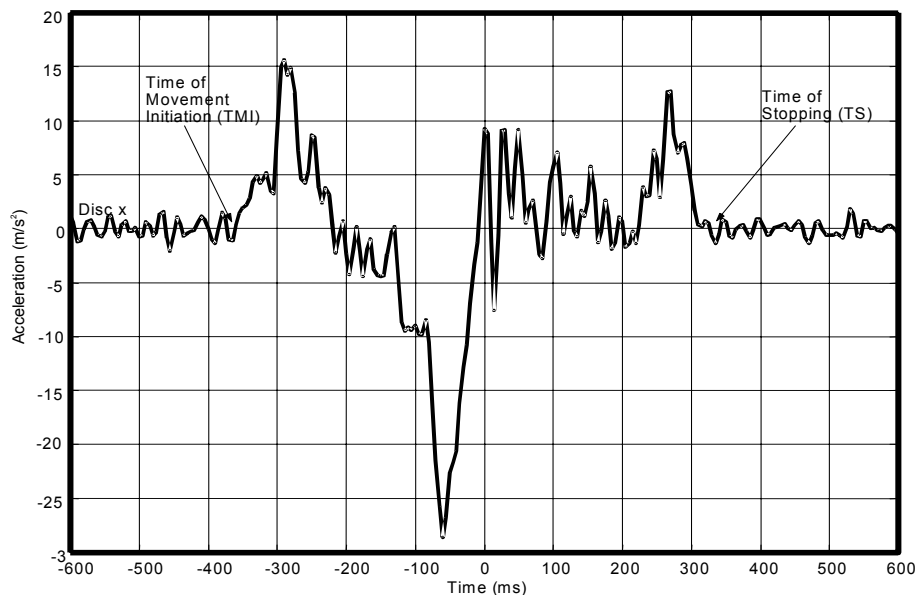


Figure 2: The figure shows how the variables TMI and TS were obtained from the acceleration curve of the disc movement. Note that the acceleration curve is a derivative of the velocity curve (Disc x) in Figure 1.

4.5 Results

The results are displayed in Table 1.

Timing of the disc movements

The MCP children initiated their movements (TMI) on average 387.6 ms before the ball hit the Plexiglas screen (the moment of collision), 24 ms later than the controls (411.6 ms). The difference in TMI was not significant. However, there was a significant difference in standard deviation between the two groups, the MCP group being more variable (S.D. = 113 ms) than the control group (S.D. = 54 ms) ($p = 0.028$, one-tailed, equal variances assumed).

The MCP children stopped their movements (TS) 241.4 ms (S.D. = 219 ms) after ball-screen contact, on average 96.8 ms later (S.D. = 90 ms) than the controls. The differences in mean TS and standard deviations of TS (193 for the MCP group vs. 113 for the control group) were not significant.

The total movement time (TMI + TS) was 629 ms (S.D. 155.8 ms) for the MCP group and 556.2 ms (S.D. 104.7 ms) for the control group, but the difference in means was not significant. However, there was a significant difference in standard deviations ($p = 0.037$, one-tailed, equal variances assumed), the MCP children being more variable than the controls.

Distances between the disc and the ball

There was a significant difference between the groups in the distance between the disc and the point at which the ball hit the screen at the moment of ball-screen collision (DC) ($p = 0.024$, one-tailed, equal variances not assumed), the MCP children being further away from their target ($M = 166.96$ mm) than their controls ($M = 97.34$ mm). In this respect there was also a significant difference between the groups in standard deviations ($p = 0.025$, one-tailed, equal variances assumed).

The mean distance between the disc and the point at which the ball hit the screen at the time the subject stopped the disc movement (DS) was 112.44 mm (S.D. = 62.40 mm) for the MCP group and 61.58 mm (S.D. = 31.44 mm) for the controls, respectively, the difference between the groups being significant ($p = 0.014$, one-tailed, equal variances not assumed). There was also a significant difference between the groups in standard deviations on this variable ($p = 0.007$, one-tailed, equal

variances assumed), the MCP group being more variable in their performance than the control group.

Table 1: The table shows means and standard deviations (S.D.) for the MCP-group and the Control group on the temporal and spatial measures of the reaching action: Time of Movement Initiation (TMI), Time of Stopping the disc movement (TS), Distance between the disc and the ball at the moment of ball-screen Collision (DC), and Distance between the disc and the ball-screen collision point at time of Stopping the disc movement (DS). The temporal measures, TMI and TS, are given in milliseconds prior to (-) and after (+) ball-screen contact respectively. TMI is also given in milliseconds after ball-release (in parenthesis). The spatial measures (DC and DS) are given in millimetres.

	MCP group		Control group		p *
	Mean	S.D.	Mean	S.D.	
TMI	- 388 (75)	100 (100)	- 412 (45)	39 (36)	n.s. (n.s.)
S.D. of TMI	113 (111)	74 (80)	54 (49)	30 (33)	0.04 (0.03)
TS	+ 241	219	+ 144	90	n.s.
S.D. of TS	193	210	113	125	n.s.
DC	167	81	97	19	0.02
S.D. of DC	78	30	50	22	0.03
DS	112	52	62	14	0.01
S.D. of DS	62	27	31	15	0.01

* T-test for independent samples (1-tailed).

4.6 Discussion experiment 1

Temporal efficiency

Although the difference between the groups on the dependent variable TMI was not significant, it was in the expected direction, and consistent with Bairstow and Laszlo's (1989) finding that children with eye-hand co-ordination problems have longer

response initiation times to moving targets than normal children. This later movement initiation is likely to be a visuo-spatial anticipation problem, more time being needed to appreciate where the ball is heading.

The significantly larger standard deviations in time of movement initiation in the MCP children confirm their lack of consistency which, in turn, may signal poor visual perception abilities, a problem that has been repeatedly signalled in the literature (Schoemaker et al., 2001; Wilson & Maruff, 1999; Wilson & McKenzie, 1998). The visual perceptual problem would be related to interpreting spatio-temporal information, such as the speed and spatial direction of the ball in flight. However, another possibility is that the problem is not related to visual perception *per se*, but to the coupling of perception and action, i.e. to react properly to the visual stimuli.

The differences between the groups with regard to how quickly they stopped the disc movement after the ball hit the screen (TS) was in the expected direction, although not significant, and in accordance with earlier findings that children with MCP have a longer reaction time than normal controls (Henderson, Rose & Henderson, 1992).

The distance between the disc and the target

The finding that the MCP children made significant larger spatial errors and were more variable in their performance (larger S.D.'s) than the control group both at the time of ball-screen contact (DC) and at the time they stopped their movement (DS) supports Bairstow and Laszlo's (1989) contention that children with perceptuo-motor dysfunction are likely to be less accurate in spatial adjustments. Under the constraints of the present experiment where the task was to reach out to the correct spatial position, a task effected by the proximal joints of the arm, this could be a sign of poor proximal control. The fact that the difference in spatial error (both DC and DS) between the performance of the MCP group and the control group was larger at ball-screen collision time (DC) than at the time they stopped their movement (at the exact point where they thought the ball had been hitting the screen) (DS) indicate that the MCP children performed better when they were given more time. This indicates that they do not only suffer from a spatial problem, but also from a temporal problem. According to Lee (1976) the perception of the spatial and temporal aspects of a ball in flight are closely interrelated, the retinal image of the optical flow fields around the

ball providing direct information about speed, direction, distance, orientation and size relative to the observer.

Not only in movement initiation time, but also in spatial error the MCP children appeared to be more variable in performance than those without motor impairments. What would such instability indicate? Apart from visual perceptual problems already mentioned, it could be an indication of inexperience with similar kinds of task. In that respect, instability of performance could be a sign of uncertainty, or that the subject is trying out different movement strategies. Instability could also be a sign of poor motor control (i.e. as a result of slow firing rate at the neurological level).

4.7 Experiment 2: Temporal uncertainty in interception

It is perhaps not surprising that no significant temporal problems were found in either group in experiment 1, the experiment having been designed so as to minimise temporal constraints. However, a temporal problem in the MCP children that might be revealed under other constraints cannot be ruled out. Potential temporal problems can best be studied in a situation in which they are more constrained. The grasping action is a good case in that it requires fine temporal adjustments of the fingers in relation to the approaching ball if a catch is to be successful. Experiment 2 was designed to enable identification of differences between the two groups with respect to the temporal occurrence of the different phases of the grasp: movement initiation, maximal aperture and initiation of the grasp (hand closing).

4.8 Methods

Subjects

The same subjects as in experiment 1 were used.

Apparatus

A pendulum system was constructed comprising a rod of length 20-cm attached, at either end, to the ceiling by strings. A ball diameter 5-cm was fastened to the end of the rod. The pendulum, when raised from its resting position, assumed the shape of a

parallelogram and could be held in its new position by an electromagnet. The horizontal distance between the ball, held by the magnet, and the hand was 270 cm. The movement time of the pendulum was 1035 milliseconds and the mean horizontal velocity was 2.39 m/s.

The subject sat on the same chair as in Experiment 1, with the right arm secured to a black metal armrest, thereby restricting the catching movement to distal control only. The armrest could be adjusted to the length of the lower arm of the subject and was fixed to a table 70 cm broad, 40 cm wide and 68 cm high. The experiment was carried out in the same room as Experiment 1, the same five ProReflex cameras and recording system being used as in the first experiment. Reflexive markers were placed on the nail of the thumb, the nail of the middle finger and on the pendulum (11 cm behind the ball). The three dimensional position (x, y, and z) of the markers were recorded by five ProReflex cameras (model MCU 240) as described under Experiment 1.

Testing procedure

The subject was seated behind the desk with the hand placed in the armrest and was told to make a clean catch of the ball. It was stressed that it was important to catch the ball before it made contact with the back of the hand and that the hand should be closed (i.e., the thumb and the middle finger together) between trials. If this did not occur, the experimenter reminded the subjects of the requirement to close the hand before the ball was released. If the subject did not manage to grasp the ball before it hit the back of the hand the trial was not repeated, in order to avoid that an increased number of trials would cause a learning effect. The subjects were given three practice trials before actual testing began and then a further seven trials were completed, with 10- to 15- sec. intervals between trials. Instructions and advice were given during the three practice trials. The whole testing procedure lasted for about 10 minutes. The first six trials, after the three practice trials, were selected for statistical analyses. The seventh trial (after the three practice trials) was performed in order to ensure enough data, in case one of the trials 4-9 failed (i.e. due to technical problems). In seven cases (four MCP children and three controls) one of the six trials intended for analyses had to be replaced by the seventh trial due to fall out of reflexive markers.

Analyses

Video analyses were obtained using the same setup as in Experiment 1. For each frame of the ProReflex recordings, from the release of the ball until the ball was in the hand, the x, y and z positions (three dimensions) of the thumb, the middle finger and the ball were obtained. From these data the aperture of the hand was calculated and plotted against the time of contact between the ball and the hand.

Dependent variables

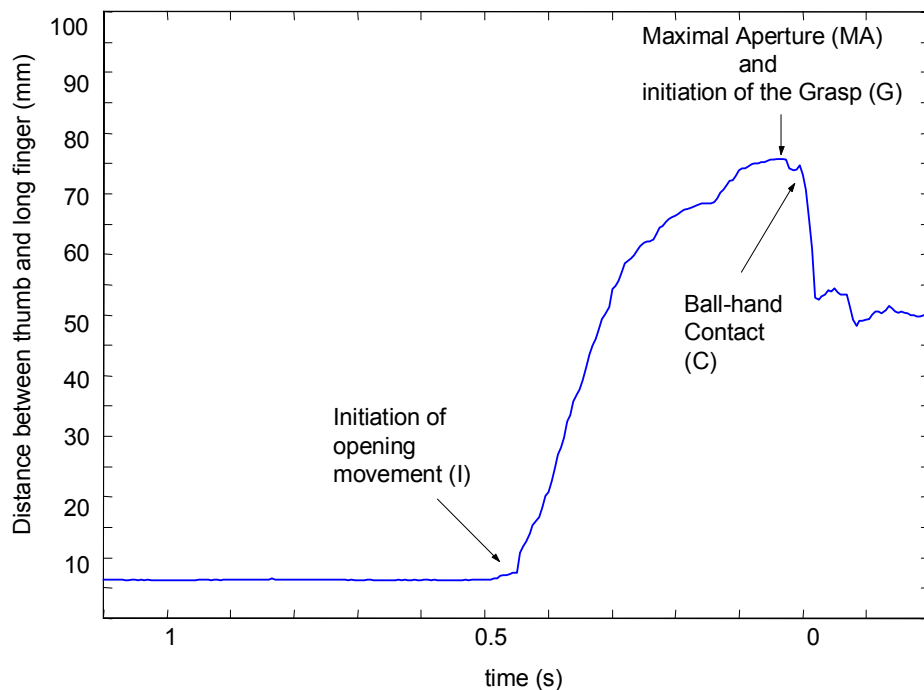
The grasping action was divided up into different phases identified by the dependent variables illustrated in Figure 3a and b.

Time of Initiation of Ballistic Opening Movement (I): Time prior to ball hand contact that the first ballistic opening movement of the fingers was initiated. This was indexed by an increase in acceleration above 2 standard deviations of mean baseline value (0) and where the velocity remained positive more than 100 ms.

Time of Maximal Aperture (MA): The point in time, between the Initiation of the Ballistic Opening Movement (I) and Ball-Hand Contact (C) at which the distance between thumb and middle finger was the greatest, computed by subtracting the y-values of the thumb from those of the middle finger.

Time of Grasping the Ball (G): Time, prior to ball hand contact, at which the ballistic grasping action was initiated. Some children tended to open up early and make two or more closing movements before contact with the ball. Time of grasping (G) was, thus, defined as the last ballistic closing movement before ball-hand contact. This variable was identified as the point in time before ball-hand contact when the velocity (of the distance between thumb and middle finger) changed from positive to negative (i.e. passed 0).

a) Typical example of plots of the ball catching action for a normal child.



b) Typical example of plots of the ball catching action for a MCP child.

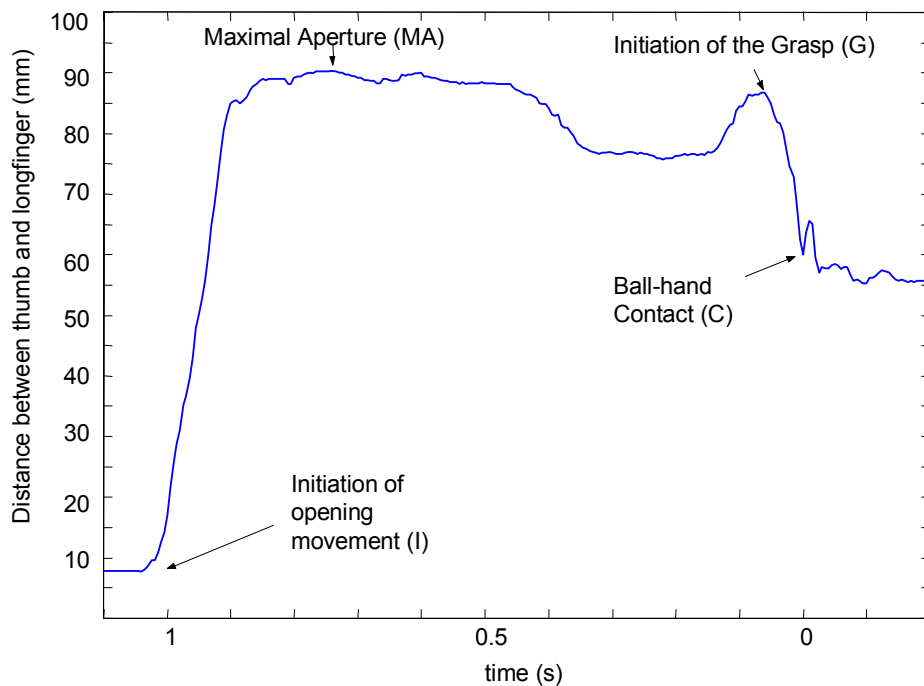


Figure 3: Data plots of the hand aperture (distance in mm between thumb and middle finger), showing how the different variables were identified: time of Initiation of ballistic opening movement (I), time of Maximal Aperture (MA), time of initiation of Grasping movement (G), and time of ball-hand Contact (C). Time is measured in seconds prior to ball-hand Contact (C) (=0) .

Time of Ball-Hand Contact (C): The point in time at which the released ball came into contact with the hand of the subject. This point was identified as the point in time at which the horizontal acceleration of the ball started to increase above 2 standard deviations of mean baseline value.

Smoothness of the Grasping Movement (SGM): A smooth grasping movement includes one opening and one closing phase accompanied by relatively few changes in acceleration. However, a less smooth grasping movement may contain several opening and closing subcomponents and correspondingly more acceleration changes. SGM was measured by the number of zerocrossings on the acceleration profile obtained from the distance measures between the middle finger and thumb.

Smoothness of the Grasping Movement pr. unit of Time (SGM/t): Some children may have more jerky movements than others, meaning that they have more acceleration changes per unit of time. This was measured by dividing the number of zero-crossings by the duration of the whole grasping movement (from movement initiation to ball-hand contact).

4.9 Results

Analyses

The results were analysed using the same model as for Experiment 1 i.e., a comparison between the first six observations for each individual across groups, the T-test for independent samples, being employed for all comparisons.

Timing of the catching action

The standardisation procedure was to set the time for ball-hand contact (C) at 0 so that the different temporal measures would indicate time in milliseconds (ms) prior to ball-hand contact.

Table 2 shows that the children in the MCP group initiated their ballistic opening movements (I) earlier ($M = -665.9$ ms; S.D. = 212.6 ms) than the controls ($M = -374.3$ ms; S.D. = 119.8 ms), on average a mean difference of 291.6 ms, the difference was significant ($p = 0.002$, one-tailed, equal variances assumed). The S.D. for the MCP group was slightly larger ($M = 227$ ms) than that of the control group ($M = 224$ ms), but the differences were not significant.

Table 2: The table shows mean and standard deviations for the MCP-group and the Control group on the temporal measures of the grasping action: Time of initiation of ballistic opening movement (I), Time of maximal aperture between thumb and long finger (MA) and Time of the grasping action (G). The temporal measures are all given in milliseconds (ms) prior to ball-hand contact. Smoothness of the grasping movement (SGM) and Smoothness of the movement pr. unit of time (SGM/t), as indicated by the number of zero crossings (SGM/t = number of zero crossings pr. second) in acceleration, is also shown (few zero crossings indicate smoothness).

	MCP group		Control group		p *
	Mean	S.D.	Mean	S.D.	
Initiation (I)	- 666	213	- 374	120	0.00
S.D. of I	227	127	224	116	n.s.
MA	- 115	139	- 29	26	0.05
SD of MA	121	140	29	31	0.03
Grasp (G)	- 33	24	- 18	14	n.s.
S.D. of G	23	11	15	12	n.s.
SGM	33	9	23	9	0.03
S.D. of SGM	10	4	7	3	0.02
SGM/t	33	9	23	9	0.03
S.D. of SGM/t	10	4	7	3	0.02

* T-test for independent samples (1-tailed).

The MCP-group reached maximal aperture (MA) earlier ($M = -115.1$ ms; $S.D. = 138.8$ ms) than the controls ($M = -29.32$ ms; $S.D. = 25.75$ ms). In the MCP group maximal aperture (MA) occurred 550.8 ms after the initiation of the ballistic opening action compared to only 344.98 ms in the control group. The difference was significant ($p = 0.05$, one-tailed, equal variances assumed). The S.D. was considerably larger for the MCP-group ($M = 121.10$ ms) compared to the control group ($M = 28.59$ ms), and the difference was significant ($p = 0.05$, one-tailed, equal variances not assumed).

There was little difference between the groups with respect to timing of the grasp (G). The grasping action was initiated earlier by the MCP children ($M = -32.95$ ms) than by their controls ($M = -18.46$ ms), but the difference was not significant. Neither was there any significant difference in standard deviation for this measure, the S.D. being 22.55 ms for the MCP-group and 15.05 ms for the control group.

The smoothness of the grasping movement (SGM) was significantly less ($p = 0.028$, one-tailed, equal variances assumed), i.e. more zero-crossings in the acceleration profile, for the MCP group ($M = 32.79$; S.D. = 8.89) than for the control group ($M = 23.39$; S.D. = 9.07). The children in the MCP group were also more variable than the control group in this respect, as indicated by significantly ($p = 0.024$, one-tailed, equal variances assumed) larger within subject standard deviations ($M = 10.22$; S.D. = 3.72 vs. $M = 6.52$; S.D. = 3.02). The MCP children had significantly ($p = 0.028$, one-tailed, equal variances assumed) more zero crossings pr. time unit (SGM/t) than the control children ($M = 32.79$; S.D. = 8.88 vs. $M = 23.38$; S.D. = 9.07). Also on this variable there was significantly ($p = 0.024$, one-tailed, equal variances assumed) more within subject variability (as indicated by the larger S.D.'s) in the MCP group ($M = 10.22$; S.D. = 3.72) than in the control group ($M = 6.52$; S.D. = 3.02).

4.10 Discussion experiment 2

The finding that the MCP children started to open their hand earlier in time in the pendulum test is in line with the predictions made in the Introduction. One interpretation is that the MCP children, being aware of their eye-hand co-ordination problems, adopted a strategy that would allow them more time for decision making. The lower variability in these actions, as indicated by the low within subject standard deviations, suggests a consistent strategy on their part. Such a strategy could not be adopted in Experiment 1 because the difficulty in predicting where and when the ball would hit the screen would serve as an additional constraint.

The MCP children reached all phases of the grasping action (movement initiation, maximal aperture and initiation of the grasp) earlier than their controls, although the difference between the groups in grasp initiation was not significant. That, however, might be due to the fact that the short distance between thumb and

long finger provides a time frame for the ballistic action, which would be too small for significant variances to occur.

The finding that the MCP-children were significantly earlier in maximal aperture than the control group cannot be seen as an artefact of the earlier movement initiation, as the time between movement initiation and maximal aperture was larger in the MCP-children than the control group. This may be explained by the fact that MCP children tended to make more opening and closing movements during the whole grasping action, which was shown by the high number of acceleration changes (SGM). The early occurring movement initiation (I) and maximal aperture (MA) together with the high number of acceleration changes may be a strategy to compensate for temporal uncertainty. It is likely that a child who is not able to precisely estimate the time to contact would choose the strategy of opening up earlier rather than running the risk of opening up too late and not being able to catch the ball. In that case it would signal a problem in visual information processing. Another possibility why the MCP children chose this strategy might be that they have problems in tuning their finger movement to the size of the ball as a result of poor proprioception. The jerky movements (SGM/t) shown by the MCP children could be related to a proprioceptive problem as well as to an underlying timing deficit. Jerky movements, as those observed here, are typically associated with cerebellar deficits, as patients with cerebellar lesions usually have problems in performing smooth directed movements.

4.11 General discussion

The purpose of the two experiments reported was to discover to what extent MCP children experience problems when their behaviour is constrained spatially or temporally in interaction with a dynamic environment. The results confirmed that the MCP children differed from normal controls in a number of respects.

Although there was a tendency for the MCP children to initiate their movements later in the reaching task (TMI), the opposite tendency was found for movement in the initial phase of the grasping task (Experiment 2) - the MCP children initiating their opening movement (I) earlier. One may speculate whether these late and early movement initiations in the two different tasks reflect a coping strategy to

compensate for weaknesses of which the MCP children have become aware. This explanation would be consistent with research by Henderson, Rose and Henderson (1992) who suggest those children with visual-perceptual problems may try to overcome their deficit by changing the initiation time of their movements. Under the constraints imposed by Experiment 1, an efficient way, in this respect, would be to wait and see where the ball is going to land, before initiating a movement in that direction. Correspondingly, an efficient way to overcome the temporal constraints in the grasping task in Experiment 2 would be to initiate movement early to allow a greater tolerance band for hand opening. For this reason, the early movement initiation in grasping would seem to reflect more or less the same problem as the late movement initiation in reaching, namely, a problem with the pick-up of visual information from a moving display (Henderson & Hall, 1982). A suggestion for further studies would be to include a “normal” catching task that comprises of both components (i.e., reach and grasp). This could confirm the hypothesis that the late movement initiation time (TMI) for the DCD group is compensated for by early hand opening movements.

However, this does not mean that a proprioceptive problem can be discarded. The jerky finger opening movements may well be related to poor proprioception. In addition Sigmundsson et al. (1997a,b) have demonstrated that younger groups of children with poor eye-hand co-ordination experience problems on pure proprioceptive tests (where vision is not involved), and that these problems are more pronounced in the non-dominant hand. Applying the same kind of proprioceptive tests as those used by Sigmundsson et al., as well as tests of visual functioning to the present group of children would help to explain whether the observed motor problems are related to an underlying problem in the visual or proprioceptive modality.

It might well be that one underlying neural disorder, such as for example a temporal problem, could give rise to proprioceptive as well as visual problems. The jerky movements may be a manifestation of such a problem. Considering that jerky movements are typical signs of cerebellar deficits, this could be a plausible hypothesis.

One intriguing possibility that the methodology used in these two experiments provides is that of distinguishing between deficiencies which manifest themselves in proximal control (Experiment 1) and those that manifest themselves in distal control (Experiment 2). Sigmundsson, Whiting and Ingvaldsen (1999b) have previously used

this kind of paradigm in an experiment with MCP children. The novelty of this approach is that it allows some statements to be made about the brain/behaviour interface. This issue was raised in the Introduction in reference to Jeannerod's (1994) contention that reaching and grasping correspond to two different visuomotor channels.

As, in these experiments, the MCP children appeared to demonstrate difficulties in reaching as well as in grasping, their problem may lie in the control of the large proximal muscle groups as well as the fine distal manipulative movements.

Based upon the data provided by these two experiments three candidate explanations are suggested:

1. MCP children, like the sample of this study, show fundamental and specific neurological problems.
2. MCP children have a lack of training and experience in tasks of this nature (interacting with a moving display), as suggested by Bairstow and Laszlo (1989), their obvious co-ordination difficulties leading them to avoid situations of this kind in everyday life.
3. The MCP children adopt a conscious strategy in order to compensate for some fundamental spatial and/or temporal inadequacies, of which they may be aware.

Distinguishing between these three explanations must, necessarily, await further empirical work. However, the explanations are not incompatible. If these children have a neural deficit (1) that causes problems in tasks like ball catching, they will avoid ball-catching activities in every day life. This will lead to a lack of experience in tasks of this kind (2). When exposed to such tasks they will adopt a certain strategy (3), as indicated in the present study, to compensate for their inadequacies.

The present study shows clearly that motor impaired children are poor in spatial skills under temporal constraints. It is very likely that some underlying neural deficit may explain these problems observed at the level of behaviour. Further studies are necessary to assess what kind of biological deficit could account for such problems as those observed here. Follow-up studies aiming at answering this question are recently being conducted at our laboratory.

In conclusion, the discriminative findings of these two experiments suggest that the kind of paradigm put forward may lead to new insights into the aetiology of co-ordination disorders as exhibited by the MCP children who served as subjects.

This optimism is based upon the fact that in making the proximal/distal distinction and relating it to spatial and temporal deficits a window is opened into more precise explanations of the locus of hand-eye co-ordination problems in children with poor movement co-ordination.

4.12 References

- Alderson, G.J.K., Sully, D., & Sully, H. (1974). An operational analysis of a one-handed catching task using high-speed photography. *Journal of Motor Behaviour*, 6, 217-226.
- American Psychiatric Association (1987). Diagnostic and statistical manual of mental disorders (3rd ed). Washington, DC: American Psychiatric Association
- Bairstow, P.J. & Laszlo, J.I. (1989). Deficits in the planning, control and recall of hand movements in children with perceptuo-motor dysfunction. *British Journal of Developmental Psychology*, 7, 251-273.
- Goodale, M.A. & Milner, A.D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences*, 15, 20-5.
- Gubbay, S.S. (1975). *The clumsy child. A study of developmental apraxic and gnostic ataxia*. London: W.B Saunders.
- Henderson, S.E. & Hall, D.M.B. (1982). Concomitants of clumsiness in young school children. *Developmental Medicine and Child Neurology*, 24, 461-467.
- Henderson, L., Rose, P., & Henderson, S. (1992). Reaction time and movement time in children with a developmental co-ordination disorder. *Journal of Child Psychology and Psychiatry*, 33, 895-905.
- Henderson, S. & Sugden, D. (1992). *The movement assessment battery for children*. Kent: The Psychological Corporation.
- Jeannerod, M. (1981). *Intersegmental co-ordination during reaching at natural visual objects*. In: J. Long & A. Baddeley (eds). Attention and performance IX. Hillsdale: Earlbaum, pp 153-168.
- Jeannerod, M. (1984). The timing of natural prehension movements. *Journal of Motor Behaviour*, 16, 235-254.
- Jeannerod, M. (1986). Mechanisms of visuomotor coordination: a study in normal and

- brain-damaged subjects. *Neuropsychologia*, 24, 41-78.
- Jeannerod, M. (1994). The hand and the object: the role of the posterior parietal cortex in forming motor representations. *Canadian Journal of Psychology*, 72, 535-541.
- Jeannerod, M., Arbib, M.A., Rizzolatti, G., & Sakata, H. (1995) Grasping objects: The cortical mechanisms of visuomotor transformation. *Trends in Neurosciences*, 18, 314-320.
- Lee, D.N. (1976). A theory of visual control in braking based on information about time-to-collision. *Perception*, 5, 437-459.
- Mæland, A.F. (1992). Identification of children with motor co-ordination problems. *Adapted Physical Activity Quarterly*, 9, 330-342.
- Savelsbergh, G.J.P., Whiting, H.T.A., & Bootsma, R.J. (1991). 'Grasping' tau! *Journal of Experimental Psychology: Human Perception and Performance*, 17, 315-322.
- Savelsbergh, G.J.P., Whiting, H.T.A., Burden, A.M., & Bartlett, R. (1992). The role of predictive visual temporal information in the co-ordination of muscle activity in catching. *Experimental Brain Research*, 89, 223-228.
- Savelsbergh, G.J.P., Whiting, H.T.A., Pijpers, R.P., & van Santvoord, T. (1993). The visual guidance of catching. *Experimental Brain Research*, 93, 148-156.
- Schoemaker, M.M., van der Wees, M., Flapper, B., Verheij-Jansen, N., Scholten-Jaegers, S., & Geuze, R.H. (2001). Perceptual skills of children with developmental co-ordination disorder. *Human Movement Science*, 20, 111-133.
- Sigmundsson, H., Ingvaldsen, R.P., & Whiting, H.T.A. (1997a). Inter- and intra-modal matching in children with hand-eye co-ordination problems. *Experimental Brain Research*, 114, 492-499.
- Sigmundsson, H., Ingvaldsen, R.P., & Whiting HTA (1997b). Inter- and intra-sensory modality matching in children with hand-eye co-ordination problems: exploring the developmental lag hypothesis. *Developmental Medicine and Child Neurology*, 39, 790-796.
- Sigmundsson, H., Whiting, H.T.A., & Ingvaldsen, R.P. (1999a). 'Putting your foot in it'! A window into clumsy behaviour. *Behavioural Brain Research*, 102, 129-136.
- Sigmundsson, H., Whiting, H.T.A., & Ingvaldsen, R.P. (1999b). Proximal versus

- distal control in proprioceptively guided movements of motor-impaired children. *Behavioural Brain Research*, 106, 47-54.
- Sugden, D. & Sugden, L. (1990). The assessment of movement skill problems in 7- and 9-year old children. *British Journal of Educational Psychology*, 61, 329-345.
- Wall, A.E. (1982). *Physical awkward children: A motor development perspective*. In: J.P. Das, R.F. Muhcahy, A.E. Wall (eds). *Theory and research in learning disabilities*, New York: Plenum Press.
- Wilson, P.H. & Maruff, P. (1999). Deficits in the endogenous control of covert visuospatial attention in children with developmental co-ordination disorder. *Human Movement Science*, 18, 421-442.
- Wilson, P.H. & McKenzie, B.E. (1998). Information processing deficits associated with developmental co-ordination disorder: A meta-analysis of research findings. *Journal of Child Psychology and Psychiatry*, 39, 829-840.

Chapter 5

VISUAL VERSUS PROPRIOCEPTIVE EXPLANATIONS OF POOR MOVEMENT CO-ORDINATION IN CHILDREN

5.1 Abstract

In an earlier study the performance of eight 10-11 year old children with movement co-ordination problems (MCP) was shown to be significantly worse than a matched group of controls on spatial and temporal parameters. Three putative deficiencies were put forward to explain these differences: in the visual system, in the proprioceptive system or in the matching of visual to proprioceptive (or *vice-versa*) information. In order to determine the viability of one or more of these explanations *the same groups* of children were tested on three different visual tasks (stemming from the magnocellular deficit theory) and two sensory matching tasks - proprioceptive and visual/proprioceptive - stemming from the inter/intrahemispheric deficit hypothesis. The results showed the MCP group to be significantly poorer than the control group on all three visual test conditions as well as the condition where visual location of a target had to be matched proprioceptively with the right hand. No significant differences between the groups were found in those conditions where the subjects had to depend on proprioceptive information only.

5.2 Introduction

The incidence of Developmental Co-ordination Disorders (DCD) in school-aged children, has been reported to be in the region of 5-6% (DSM-IV, APA, 1994). With an eye on prevention and intervention, many recent research endeavours have been directed towards identifying putative underlying dysfunctions at various levels of neuropsychological analysis. For example, in a recent study Estil, Ingvaldsen and Whiting (2002) focused on the reaching and grasping subactions of one-handed ball catching in a group (n=8) of 10 and 11 year-old children with movement co-ordination problems (MCP). They were shown to initiate their reaching movements later and to make larger spatial errors than their age-matched controls (n = 8). They were also shown to start to open up the fingers of their catching hand earlier in time

before ball-hand contact and to reach maximal aperture earlier. Variability in the time of appearance of maximal aperture in this group of MCP children was also greater.

In an attempt to identify the nature of the deficits that lead to these inconsistencies, Estil et al. (2002) were led to speculate that they were the consequence of: visual deficits in the perception of the trajectory of the ball, proprioceptive deficits in the control of their hand movements or, a problem in matching visual and proprioceptive information.

Support for the visual deficit hypothesis is provided in a recent study by Lefebvre and Reid (1998) which showed that a group of 5-7 year-old motor impaired children (n=40) were significantly worse in predicting ball flight trajectories (at most viewing times) than a normal control group (n=46). Questions about the underlying neuropsychological deficits that might have given rise to this problem were left open.

In searching for possible explanations, one is attracted to the magnocellular deficit theory of Stein and Walsh (1997), albeit conceived in the context of dyslexia⁸. The visual system may be subdivided into magnocellular and parvocellular functioning. Magnocellular functioning is mediated by large nerve cells (magnocellular) that form a pathway from the retina, via the lateral geniculate nucleus, to the visual cortex. Their thick myelin sheet enables them to carry electrical impulses faster than other nerve cells leading them to play a crucial role in informing the visual cortex about rapid changes in events or movements in the environment. The magnocellular system is also concerned with the control of eye movements and the stabilisation of binocular function. A plausible hypothesis, therefore, is that the movement problems of some poorly co-ordinated children, particularly with reference to moving objects in the environment, are a consequence of magnocellular processing inadequacies. Their problem in shaping their hands relative to the size of the ball could, in turn, be attributed to deficiencies in the functioning of the parvocellular visual system which consists of smaller cells that play a major role in the processing of information about pattern, shape and colour of stimulus objects.

⁸ The magnocellular theory of dyslexia mainly has its origin in a post mortem study of five dyslexic brains, by Galaburda and colleagues (Livingstone et al., 1991), which showed that the magnocellular layers of the lateral geniculate nucleus were disordered, and that the magnocellular cells were 20% smaller than in normal brains. Also, psychophysical studies have shown that dyslexics have reduced sensitivity at low spatial frequencies and luminance levels favoured by the magnocellular system, whereas they have normal sensitivity in higher spatial frequencies served by the parvocellular system (Lovegrove et al, 1980).

Even if this interpretation should prove to have explanatory power it does not, necessarily, mean that proprioceptive problems might not also be present and contributing to, for example, poor motor co-ordination in children on tasks involving a major movement component. That such a statement might be justified is confirmed by Sigmundsson, Ingvaldsen & Whiting's (1997a,b; Sigmundsson, Whiting & Ingvaldsen, 1999) demonstration that younger groups (age range 7-8 years) of motor impaired children often experience problems on pure proprioceptive tasks (where vision is not involved).

Wilson and McKenzie (1998), in a meta-analysis of information processing deficits associated with developmental co-ordination disorders also showed that while the greatest deficiency was found in visual-spatial processing, deficiencies in the small-to-moderate range were also found for kinaesthetic (perception of limb movement and limb position) and cross-modal processing (the transfer of information between sensory modalities).

With these possible explanations and theoretical interpretations as background, the present study was designed to assess the viability of the three deficit explanations – visual and proprioceptive processing - in the group of children used as subjects in the ball-catching study of Estil et al. (2002).

5.3 Method

Subjects

The same 10-11 year old (range 10 years, 5 months to 11 years, 4months) subjects as in the Estil et al study (2002) took part in the testing programme, with the exception of three children who moved to a different part of the country before the data collection was completed. Thus, a MCP group of n=8 and a control group of n=7 completed the visual task, while a MCP group of n=6 and a control group of n=7 completed the hand-hand and foot-hand matching tasks.

Procedure

Tests of magno and parvo cellular functioning (visual perception)

The child was seated in front of a computer screen and was required to determine on which side of the screen (right or left) a particular pattern of white dots against a black background occurred (for details, see Hansen, Stein, Orde, Winter and Talcott, 2001). The task was made increasingly more difficult over trials. Three conditions were used:

Form 1: The children had to identify a circular figure within a pattern of dots, which could be at different locations (requiring visual search). This task requires both magno-and parvocellular functioning: pattern identification being dependent on parvocellular functioning and the visual search component on magnocellular functioning.

Form 2: As in Form 1, the children had to identify a circular pattern, but this time the pattern was always in the same position. As this procedure removed the need for visual search, the task would be mainly dependent on parvocellular functioning.

Motion: On this task moving dots appeared on the screen. The requirement was to determine on which side of the screen (right or left) the dots moved back and forth and not in a random order. Performance on this task depends, in the main, on magnocellular functioning.

Hand-hand matching (cross-modal perception)

A table top apparatus (see Sigmundsson et al., 1997a,b for details) was used, which required the subject to match the position of the index finger of the one hand with that of the other. Six different conditions were used:

- Vision Proprioception Right hand matching (VPR):
The subject is required, under visual guidance of the movement, to locate the target pin with the left hand on top of the tabletop and match its position, with the right hand, on the underside of the tabletop.
- Vision Proprioception Left hand matching (VPL):
The same procedure as for VPR, the right hand now being used for location and the left hand for matching.
- Vision Right hand matching (VR):
Visual (without proprioceptive) location of the target, and right hand matching.

- Vision Left hand matching (VL):
The same procedure as for VR but, now, with left hand matching.
- Proprioception Right hand matching (PR):
Proprioceptive location of the target (without visual feedback) with the left hand, and matching with the right hand.
- Proprioception Right hand matching (PL):
The same as for PR but, now, with right hand location and left hand matching.

Foot-hand matching (proprioception)

The foot-hand-matching task utilised a small Plexiglas tabletop (for details, see Sigmundsson et al., 1999). A target pin (a marker pin with a radius of 2.5mm) was attached to the underside of the table and the centre of the subject's big toe could be made to coincide with this position. The subject was required to match the position of the big toe with the hand (on top of the table) on the same or opposite side of the body without the use of visual feedback. Four conditions were used:

Right foot location/Right hand matching (RfRh)

Right foot location/ Left hand matching (RfLh)

Left foot location/ Left hand matching (LfLh)

Left foot location/Right hand matching (LfRh)

In both the hand/hand test and the foot/hand test four trials were required for every condition, and mean error and standard deviation across the four trials for each subject were computed.

5.4 Results

Vision

The MCP group was shown to be poorer in performance than the normal group on all three visual test conditions (form 1, form 2 and motion), all differences being significant at the 5% level (Table 1).

Table 1: Mean scores and SDs for each of the three visual tests (Form 1, Form 2, and Motion) for the differences between the two groups.

	Motor impaired (n = 8)		Normal group (n = 7)		P*
	Mean	SD	Mean	SD	
Form 1	31.53	3.96	23.00	2.75	0.00
Form 2	23.38	5.19	18.42	2.94	0.03
Motion	11.68	2.15	9.56	3.16	0.05

* Mann Whitney U test (one-tailed)

Hand-Hand Matching

Significant differences between the groups were found only for the “Vision Right hand matching” (VR) condition ($p = 0.02$, Mann Whitney U, one-tailed), the MCP group being poorer in performance than the control group (mean 16.75 vs. 10.25 mm; SD 6.35 vs. 3.31). The performance of the MCP group and the control group respectively on the remaining conditions were as follows: “Vision Proprioception Right hand matching” (VPR) (mean 18.46 vs. 14.29 mm; SD 9.73 vs. 4.93), “Vision Proprioception Left hand matching” (VPL) (mean 15.04 vs. 15.25 mm; SD 5.85 vs. 4.41), “Vision Right hand matching” (VR) (mean 16.75 vs. 10.25 mm; SD 6.35 vs. 3.31), “Vision Left hand matching” VL (mean 12.89 vs. 14.32 mm; SD 5.83 vs. 5.59), Proprioception Right hand matching” (PR) (mean 32.08 vs. 22.43 mm; SD 12.97 vs. 9.62), and “Proprioception Left hand matching” (PL) (mean 29.71 vs. 25.96 mm; SD 12.07 vs. 7.95) (Figure 1).

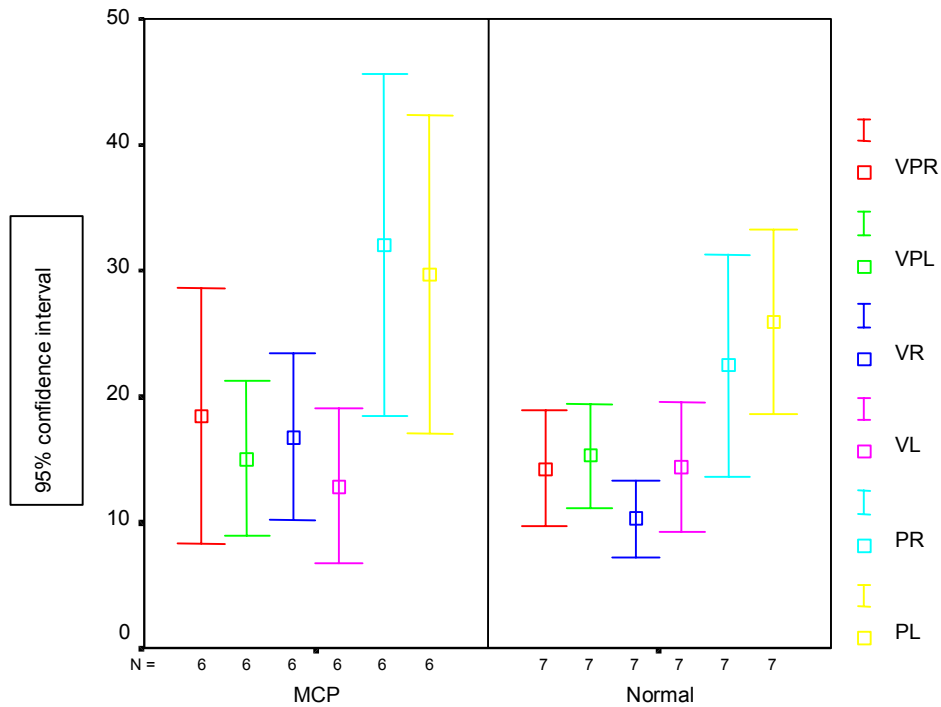


Figure 1: Boxplot showing mean error values (mm) for the MCP group and the normal group on the different conditions (see methods section) of the hand-hand-matching task.

Foot-Hand Matching

There were no significant differences between the groups on the Foot-Hand matching task. The performance of the MCP group and the control group respectively were as follows: “Right foot location Right hand matching” (RfRh) (33.29 vs. 30.32 mm; SD 12.72 vs. 12.76), “Left foot location Right hand matching” (LfRh) (41.71 vs. 34.71 mm; SD 5.36 vs. 4.26), “Right foot location Left hand matching” (RfLh) (37.00 vs. 37.26 mm; SD 12.36 vs. 17.80) and “Left foot location Left hand matching” (LfLh) (28.96 vs. 38.36 mm; SD 3.46 vs. 5.92).

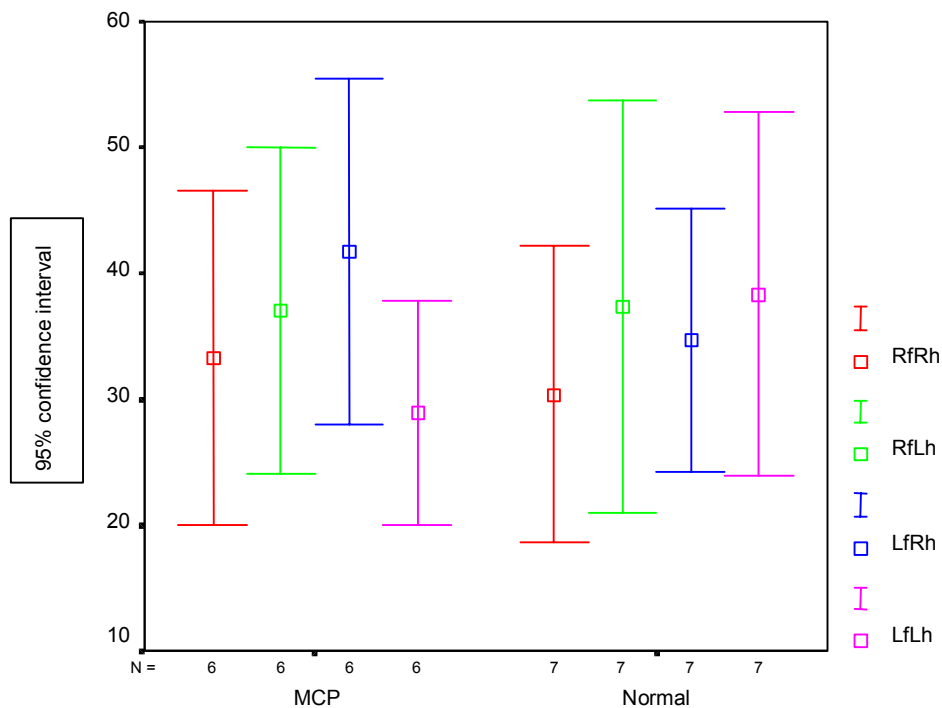


Figure 2: Boxplot showing mean error values (mm) for the MCP group and the normal group on the different conditions (see methods section) of the foot-hand-matching task.

5.5 Discussion

The results confirmed the Wilson and McKenzie (1998) finding that the major deficiency in MCP children, identified as for this and the earlier study (Estil, Ingvaldsen & Whiting, 2002), is in visual processing. It is striking that the present group of MCP children performed poorly on all three visual conditions when compared to the control group children. Moreover, it would appear that MCP children have more severe visual information processing problems even than dyslexics, who have been shown to experience problems only on the motion task (Hansen et al., 2001). It has, however, to be remembered that the present group of MCP children were not screened for reading deficits leaving the possibility that these could have biased some of the results.

As for the two matching tasks, the finding of a significant difference between the groups on the condition visual localisation and Right hand matching (VR) only provides support for the idea of a visual-to-proprioceptive matching problem, i.e.

combining visual input information with proprioceptive output. For some reason the right hand (which in the main is controlled by the left hemisphere) seems to have problems in getting tuned to the visual information. This could either be due to a visual and/or proprioceptive deficit. However, as the MCP group was not impaired in any of the pure proprioceptive conditions (i.e. without visual information), but was significantly inferior in all conditions of the visual tests it is possible that the Vision-Right hand matching (VR) problem is associated with a visual information processing deficit within the left hemisphere, rather than a right hand proprioceptive deficit *per se*. The natural question which then arises is: “Does this task require a kind of visual processing that is normally associated with left hemispheric processing?” Remember that the task (VR) was to visually localise one particular dot (local information) within a circle (global information). An interesting link is to be found in a study by Sergent (1982) where the left hemisphere was found to be better at representing local information (i.e. identifying small letters within larger letters) while the right hemisphere was better with global information (identifying the larger letters rather than the many small letters they were composed of). Further, Robertson and colleagues (1988) have found that problems with visual object recognition are associated with damage that encompasses the temporal and parietal lobes. This rhymes well with the poor performance on the visual parvocellular test, as visual information from the parvocellular cells, that are specialised at object recognition, in the main is projected to the temporal lobe.

Considering the Sigmundsson et al’s studies (Sigmundsson, 1999; Sigmundsson et al., 1999), in which eight-year old children with hand-eye co-ordination problems were found to have problems in transferring proprioceptive information from right to left hand (when vision was excluded) in an intra-modal matching task, and for three conditions (RfLh, LfRh and LfLh) in an inter-modal matching task, it is surprising that no such proprioceptive problems were observed in the present group of MCP children.

An important clue here might be the age of the children. Whereas the children in the Sigmundsson et al studies (Sigmundsson, 1999; Sigmundsson et al., 1997a, 1997b, 1999) were in the age range 5-8 years, the children participating in the present study were around the age of 11 years. One of the interpretations of the Sigmundsson et al. findings was a developmental lag in proprioceptive perception due to delayed maturation of the corpus callosum (Sigmundsson, 1999; Sigmundsson et al., 1997a,

1997b, 1999). If this should prove to be the case, one of the interpretations of the findings of the present study would be that, by the age of eleven years, the lag was no longer present. This would be along the lines of the observation of Trevarthen (1974) that the corpus callosum is one of the last brain structures to reach maturity, and matures gradually over the first 5 to 10 years of human life.

In conclusion, all the results taken together suggest that the fundamental problem in the present group of children be related to visual perception. The deficit could be related to the magno- and parvocellular cells *per se*, or to higher level processing. Further research is necessary in order to make more clear statements about the nature of the visual perceptual problems in MCP children and to investigate the hypothesis of a developmental lag as related to the corpus callosum. Longitudinal studies would be required for further investigation of the developmental lag hypothesis.

5.6 Acknowledgements

This study is an extension of two studies, one on ball catching in children with movement co-ordination problems (Estil, Ingvaldsen and Whiting, 2002) and the other on magno/parvo cellular functions in poorly co-ordinated children (Sigmundsson, Hansen, and Talcott, in preparation). The latter study was developed in co-operation with John Stein's laboratory (University Laboratory of Physiology, Parks Road, Oxford OX1 3PT) at Oxford University.

5.7 References

- American Psychiatric Association (1994). *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.). Washington DC: Author.
- Estil, L.B., Ingvaldsen, R.P., & Whiting, H.T.A. (2002). Spatial and temporal constraints on performance in children with movement co-ordination problems. *Experimental Brain Research*. Accepted.
- Hansen, C., Stein, J.F., Orde, S.R., Winter, J.L., & Talcott, J.B. (2001). Are dyslexics' visual deficits limited to measures of dorsal stream function? *Neuroreport*, 12,

1527-1530.

- Lefebvre, C., & Reid, G. (1998). Prediction in ball catching by children with and without a developmental coordination disorder. *Adapted Physical Activity Quarterly*, 15, 299-315.
- Robertson, L.C., Lamb, M.R. & Knight, R.T. (1988). Effects of lesions of temporal-parietal junction on perceptual and attentional processing in humans. *Journal of Neuroscience*, 8, 3757-3769.
- Sergent, J. (1982). The cerebral balance of power: Confrontation or cooperation. *Journal of Experimental Psychology: Human perception and performance*, 8, 253-272.
- Sigmundsson, H. (1999). Inter-modal matching and bi-manual co-ordination in children with hand-eye co-ordination problems. *Nordisk Fysioterapi*, 3, 55-64.
- Sigmundsson, H., Hansen, P., & Talcott, J., in preparation.
- Sigmundsson, H., Ingvaldsen, R.P., & Whiting, H.T.A. (1997a). Inter- and intra-sensory modality matching in children with hand-eye-co-ordination problems. *Experimental Brain Research*, 114, 492-499.
- Sigmundsson, H., Ingvaldsen, R.P., & Whiting, H.T.A. (1997b). Inter- and intra-sensory modality matching in children with hand-eye-co-ordination problems: exploring the developmental lag hypothesis. *Developmental Medicine and Child Neurology*, 12, 790-796.
- Sigmundsson, H., Whiting, H.T.A., & Ingvaldsen, R.P. (1999). 'Putting your foot in it!' A window into clumsy behaviour. *Behavioural Brain Research*, 102, 129-136.
- Stein, J. & Walsh, V. (1997). To see but not to read; the magnocellular theory of dyslexia, *Trends in Neurosciences (TINS)*, 20, 147-152.
- Trevarthen, C. (1974). Cerebral embryology and the split brain. In M. Kinsbourne & W.L. Smith (Eds.), *Hemispheric disconnection and cerebral function* (pp. 208-236). Springfield, IL: Charles C. Thomas.
- Wilson, P.H. & McKenzie, B.E. (1998). Information processing deficits associated with developmental coordination disorder: A meta-analysis of research findings. *Journal of Child Psychology and Psychiatry*, 39, 829-840.

Chapter 6

Are motor and reading impairments in children related to the same, or different, visual deficits?

6.1 Abstract

This study was designed to determine whether motor and reading impairments in children are related to the same or different visual deficits. Eighty children between the ages of 10 and 11 years were required to complete the Movement Assessment Battery for Children (MABC) as well as a standardised reading test. This enabled the separating out of three groups of 8 children: a *normal* group, average or above on both reading and motor skills; a motor-impaired group with poor motor skills but normal reading skills, and a motor/reading impaired group which was poor on both motor and reading skills. The selected children were required to complete two visual tests: a test of magnocellular functioning and a test of parvocellular functioning. The results showed the motor/language impaired children to be inferior to the normal children in both magnocellular and parvocellular functioning, while those who were motor-impaired only performed inferior to the normal group on the parvocellular but not on the magnocellular test. A comparison of the two motor-impaired groups showed that the motor impaired children with reading impairment were inferior to those without reading impairment only on the magnocellular test. The results indicate that reading and motor impairments are related to deficits in two different visual functions, a magnocellular deficit related to reading impairment, and a parvocellular deficit related to motor impairment. When motor and reading impairments co-occur more extensive visual problems are likely to be encountered.

6.2 Introduction

Children with a marked impairment in motor co-ordination, not due to a general medical condition or mental retardation which significantly interferes with academic achievement or activities of daily living, have been classified as Developmental Co-ordination Disorder (DCD). The prevalence of DCD is about 6 %, and, amongst other correlates, it has been associated with phonological (frequently observed in dyslexics) and language disorders (APA, 1994). A number of studies have shown that motor-impairments often co-occur with reading problems (Fawcett & Nicolson, 1992,

1995; Fawcett, Nicolson & Dean 1996; Moore, Brown, Markee, Theberge & Zvi, 1995; Wolff, Melngailis, Obregon & Bedrosian, 1995). In trying to understand the nature of motor and reading impairments, where they occur together, it is important to ask what is the neural correlate of this constellation of problems?

A few attempts have been made to answer this question. For example, Fawcett and Nicolson (1992, 1995; Fawcett, Nicolson & Dean 1996) have shown that dyslexics tend to perform poorly on fine motor tasks that involve rapid movements and static balance. These are tasks that traditionally have been associated with cerebellar dysfunction.

Another possible answer to this question is to be found in the magnocellular deficit hypothesis of Stein and Walsh (1997). This hypothesis proposes that dyslexics suffer from a deficit in the transient, magnocellular, component of the visual processing system. The visual system may be divided into two: the transient, *magnocellular*, and the sustained, *parvocellular* sub-systems. Each of these cell types carry different information that is conveyed to different layers of the geniculate nucleus of the thalamus and then to the visual cortex. In perception, the magnocellular sub-system mainly responds to large contour, low contrast and moving targets, and is predominant in peripheral vision. The parvocellular system consists of small cells that are sensitive to form/pattern, structure and colour, and is predominant in central vision.

Considering the functional division of the magnocellular and parvocellular system it is to be expected that both magnocellular as well as parvocellular function is necessary not only for reading skills, but for the mastery of a number of motor skills as well. For example, it is anticipated that the transient, magnocellular, system is important for all motor tasks that are dependent on fast visual processing, as for example in ball games and in eye-hand co-ordination tasks where quick manual movements are involved. As in reading, the fine motor task of drawing and writing, also require visual tracking, which is dependent on the magnocellular systems activation by the saccadic eye movements. On the other hand, the sustained, Parvocellular, system is believed to be of importance in most motor tasks that are dependent on visual fixation (central vision) as, for example, in aiming, grasping and balancing tasks.

A recent study by Hansen, Stein, Orde, Winter and Talcott (2001) showed that phonetic dyslexics performed significantly poorer than controls on a motion detection

test designed to measure magnocellular function, while they did not perform different from controls on a test of pattern recognition, designed to measure parvocellular function.

Given the fact that visual problems have frequently also been reported in children with developmental co-ordination disorders (DCD)(Dewey & Kaplan, 1994), and that DCD is associated with phonological and language impairments, this suggests that the observed visual problems in these children could be due to the same kind of deficit, which could, thus, also account for the co-occurrence of motor and reading impairments in children. The study reported in Chapter 5 showed that a group of motor impaired children was inferior to a normal control group, not only on the test of magnocellular functioning, but also on that of parvocellular functioning. Based on these results it might seem that motor impaired children are suffering from an even larger deficit in the visual system than dyslexic children, a deficit that does not only encompass the magnocellular but also the parvocellular system.

In the light of the above discussion, there is a possibility that the results from Chapter 5 were confounded by the inclusion of some motor-impaired children who were also reading impaired. To tease out this potential source of confounding it would be necessary to test subgroups of motor and reading impaired children on the same tests. If those children with both motor and reading impairments were to be separated out from those with only motor-impairment, it would be predicted, on the basis of the above discussion, that the former group of children would perform poorly on the parvocellular test only, while the latter group would perform poorly on both the tests of parvo- and magnocellular functioning. The study that follows is designed to test that hypothesis.

6.3 Method

Subject selection

N = 102 children, aged 10 years and 4 months to 11 years and 4 months (mean 10.99, SD 0.28), from a city school in Norway were tested on the Movement Assessment Battery for Children (MABC). Of these, 80 children were tested on a standardised reading test (the remaining 20% were absent from school on the actual day when the reading test was given), “Kartlegging av leseferdighet for 5.klasse” (“Mapping of

reading skills for the 5th grade”) (Nasjonalt Læremiddelsenter, 1997). Based on the percentile scores on the MABC and the Reading test the children were assigned to one of three different groups, according to the following procedure: 27 children scored at or below the 15th percentile on the MABC. These were categorised, on the normally accepted criteria, as motor impaired. Those motor impaired children who scored at or below the 20th percentile in reading ($n = 8$) were assigned to the motor/reading impairment group, while those who scored at or above the 50th percentile in reading ($n = 8$) were assigned to the motor impaired only group. The remainder of the motor impaired children, scoring between the 15th and the 50th percentile on the reading test were not pursued further. A control group of $n = 8$ children was randomly selected from among those children who scored above the 50th percentile on the MABC as well as on the reading test ($n = 19$). An overview of the three selected groups is presented in Table 1.

Table 1: Overview of the three groups (Motor/reading impaired, Motor impaired only and Normal control group) with respect to gender, (L)eft or (R)ight hand preference, age, percentile score on the MABC (MABC) as well as on the reading test (READ).

Groups ($n = 8$)	Gender	Hand pref.	Age Mean (SD)	MABC Mean (SD)	READ Mean (SD)
Motor/reading impaired	6 males	R	10.83	4.63	10.24
	2 females	R	(0.33)	(5.10)	(7.81)
Motor impaired only	3 males	2R, 1L	11.03	4.88	68.98
	5 females	R	(0.26)	(4.70)	(15.20)
Control	5 males	4R, 1L	10.78	85.75	70.93
	3 females	R	(0.30)	(10.81)	(16.53)

Instruments

Movement Assessment Battery for Children (MABC)

The MABC (Henderson & Sugden, 1992) is a formalised standardised test battery to identify children with motor co-ordination problems. The test-battery is divided into 4 age bands (4-6 years, 7-8 years, 9-10 years and 11-12 years), each age band containing 8 sub-tests divided into three categories: 3 tests of manual dexterity, 2 tests

of ball skills and 3 tests of static and dynamic balance. The eight sub tests for the age band 9-10 years (as was given to the present group of children) are as follows:

- 1) Shifting pegs: in front of the child is a wooden pegboard with three rows of pegs and an empty row at the bottom. The child is required to move the pegs as fast as possible, one at a time, one row down, first with the preferred hand, and then with the non-preferred hand. The time used to complete the task is recorded.
- 2) Threading nuts: The child is required to thread three nuts on a bolt. As fast as possible. The time used to complete the task is recorded.
- 3) Flower trail: The child receives a white sheet of paper with a tulip drawn by double black lines. The child is required to draw a line with a red pen between the two lines in the tulip pattern. Numbers of errors (when the child draws outside the double line) are recorded.
- 4) Two-hand catch: The child is supposed to throw a tennis-ball at the wall and catch the ball, before it hits the ground, as it returns. Number of correct catches out of ten trials is recorded.
- 5) Throwing beanbag: This task involves throwing a beanbag into a target box from a distance of two metres. Number of «goals» out of ten trials is recorded.
- 6) One-board balance: The child is required to balance on one leg at a time on top of a wooden board. The time of retaining balance on each leg is recorded.
- 7) Hopping in squares: Five squares (45cm^2) are taped on the floor. The task is to jump on one leg, from one square to the next and to stop in the last square. Number of successful jumps is recorded.
- 8) Ball balance: The child holds a wooden plate, with a tennis ball on top of it, in one hand. The task is to walk through a trail while balancing the tennis ball on top of the wooden plate. Number of times the ball falls down are recorded.

On each sub-test the child receives a score from 0-5, 0 representing the best performance. These scores add up to a "total impairment score" (with 0 as the best score) that is interpreted relative to percentile norms provided in the test manual, where those scoring at or below the 15th percentile (those with the 15 percent poorest performance) is defined as the at risk group.

Kartlegging av leseferdighet (Mapping of reading skills)

The test is designed for the purpose of identifying children who have problems with reading, and to provide a general information about the reading capability of children. The at-risk group is defined as the 20% poorest readers in the test manual. However, it is specified in the manual, that further diagnostic procedures are necessary in order to determine causal factors and the precise nature of the reading disability. Reading speed, reading comprehension and functional reading are emphasised. The test battery contains seven sub-tests that are to be completed within a certain time constraint. Number of correct answers on each sub test is recorded. The sub-tests are as follows:

- 1) Ordavkoding – fra ord til bilde (Word decoding – from word to picture): This is as word reading task where the children on each line read one word, which is to be matched with the correct picture. Two minutes are given to complete this task.
- 2) Ordavkoding – fra bilde til ord (Word decoding – from picture to word): Same as above, but the other way around. On each line there is a picture which has to be matched with the correct word. Time constraint: 2 minutes.
- 3) Edderkopper (Spiders): This is a text with a lot of information of the kind that is often found in schoolbooks. The children are supposed to, first, read the text and, then, answer some text-related questions (multiple choice). Time constraint: 4 minutes.
- 4) Forståelse av ord i setninger (Comprehension of words in sentences): This task aims at investigating children's comprehension of words in sentences. The children are supposed to write a cross on "yes" or "no" to different statements like, for example, "Can we sing a song"? Time constraint: 3 minutes.
- 5) Da bokfinken fikk farger (When the chaffinch got its colours): Here, the children are supposed to read a text before they answer 10 questions. The questions are partly connected to direct information in the text, and partly inference questions. In order to answer the questions the children have to be able to draw conclusions on background of the information in the text. Time constraint: 4 minutes
- 6) Solsystemet (The solar system): In this task the teacher reads the text loud for the children. At the same time as the children are listening, they have to follow the text. Afterwards they have to read the questions themselves and find the

right answer on background of the information in the text. Time constraint: 2 ½ minutes.

- 7) Værmeldingen (The weather forecast): This is a short text with a weather chart. The information necessary to answer the questions is found in the text as well as on the weather chart. Time constraints: 2 ½ minutes.

Tests of magno and parvo cellular functioning

The child was seated, at a distance of 57 cm, in front of a computer screen and was required to determine on which side of the screen (right or left) a particular pattern of white dots against a black background occurred (for details, see Hansen, Stein, Orde, Winter and Talcott, 2001)⁹. The task was made increasingly more difficult over trials. Two conditions were used:

- 1) Form: The children had to identify, on a computer screen, a circular figure within a pattern of dots. This task is designed to assess the level of parvocellular functioning.
- 2) Motion: On this task moving dots appeared on the screen. The requirement was to determine on which side of the screen (right or left) the dots moved back and forth rather than in a random order. Performance on this task depends, in the main, on magnocellular functioning.

Data Analysis and Statistics

Given that neither the MABC nor the Reading test were normally distributed (as both tests have a ceiling effect) non-parametric statistics were used. Spearman's rho was utilised for correlation analysis. All statistical comparisons utilised the Mann Whitney U test, and were performed using the SPSS (version 8.0) statistical package for Windows.

⁹ These tests were devised by Peter Hansen in co-operation with John Stein at the University Laboratory of Physiology, Oxford University, UK.

6.4 Results

There were no significant differences in age, handedness or gender distribution between the groups (Mann Whitney U, two-tailed). There were no significant correlations (Spearman's rho, two-tailed) between age, gender or hand preference on any of the dependent variables (magno and parvo), with correlations ranging from 0.008 to 0.08.

Group comparisons

The group comparisons (Table 2) showed that the motor/reading impaired children were significantly poorer than the normal children in both magnocellular (Mean 14.51, SD 4.19 vs. Mean 9.13, SD 2.52; $p = 0.005$) as well as parvocellular (Mean 19.93, SD 3.75 vs. Mean 27.14, SD 6.57; $p = 0.014$) functioning, while those who were motor impaired only were significantly ($p = 0.005$) poorer than the normal group on the parvocellular (Mean 25.08, SD 2.97 vs. Mean 19.93, SD 3.75) test only. A comparison of the two motor impaired groups showed that those who were reading impaired were inferior to those without reading impairment on the magnocellular test only (Mean 14.51, SD 4.19 vs. Mean 9.13, SD 2.52; $p = 0.005$).

Table 2: Mean scores and SDs for each of the two visual tests, magnocellular function (Magno) and parvocellular function (Parvo), for each of the two motor impaired groups (with and without reading impairment) and the control group (no motor or reading impairment) together with the p-values for the differences between the motor impairment groups compared to the control group (*) as well as with each other (**).

Test	Control	Motor impaired only	Motor/reading impaired			
	($n = 8$)	($n = 8$)	($n = 8$)	($n = 8$)	($n = 8$)	($n = 8$)
	Mean (SD)	Mean (SD)	p^*	Mean (SD)	p^*	p^{**}
Magno	9.13 (2.52)	9.73 (2.44)	n.s.	14.51 (4.19)	0.005	0.005
Parvo	19.93 (3.75)	25.08 (2.97)	0.005	27.14 (6.57)	0.014	n.s.

* and ** Mann Whitney U test (one-tailed)

Correlations

Correlations (Spearman's rho, one-tailed) between the dependent variables magno- and parvocellular function, the total scores as well as the subtests of the MABC and the Reading test revealed stronger relations to levels of parvocellular function than to magnocellular function, both in relation to the total score on the MABC (rho 0.401, $p = 0.002$ vs. 0.366, $p = 0.005$) as well as that of the Reading test (rho 0.325, $p = 0.015$ vs. rho 0.285, $p = 0.035$). It is interesting to note that both tests of visual functioning are stronger related to general motor performance than to reading, the relation to motor performance being stronger for the parvocellular test than for the magnocellular test. When looking at the individual sub tests (see Table 3) of the MABC, both magno and parvocellular function correlates significantly (one-tailed) with Shifting pegs (rho 0.566, $p = 0.002$ and rho 0.347, $p = 0.041$), Throwing bean bag (rho 0.362, $p = 0.035$ and rho 0.398, $p = 0.022$) and One-board balance (rho 0.386, $p = 0.026$ and rho 0.490, $p = 0.005$). Only magnocellular function correlates significantly with Flower trail (rho 0.374, $p = 0.030$), while only parvocellular function correlates significantly with Two hand catch (rho 0.364, $p = 0.034$), Hopping in squares (rho 0.462, $p = 0.009$), and Ball balance (rho 0.420, $p = 0.016$).

With respect to the Reading sub tests, both magno and parvocellular function correlates significantly with "The chaffinch" (rho 0.251, $p = 0.027$ vs. rho 0.226, $p = 0.043$) and "The solar system" (rho 0.386, $p = 0.002$ vs. 0.263, $p = 0.044$). Only magnocellular (and not parvocellular) function correlates with the sub test "Comprehension of words" (rho 0.228, $p = 0.041$, one-tailed), while only parvocellular function correlates with the sub tests "From word to picture" (rho 0.400, $p = 0.001$, one-tailed) and "From picture to word" (rho 0.262, $p = 0.023$, one-tailed).

Table 3: Correlations (Pearson' rho, one tailed), together with level of significance (p), and number of cases (N), between the dependent variables, magno- and parvocellular function, and the total scores as well as the individual sub tests of the MABC and the Reading test.

MABC/Reading sub test	Magnocellular function			Parvocellular function		
	Spearman's rho	p	N	Spearman's rho	p	N
Shifting pegs (MABC)	0.566	0.002	26	0.347	0.008	26
Threading nuts (MABC)	- 0.028	n.s	26	- 0.067	n.s	26
Flower trail (MABC)	0.374	0.003	26	0.241	n.s	26
Two-hand catch (MABC)	0.152	n.s	26	0.364	0.034	26
Throwing bean bag (MABC)	0.362	0.035	26	0.398	0.022	26
One-board balance (MABC)	0.386	0.026	26	0.490	0.005	26
Hopping in squares (MABC)	0.044	n.s.	26	0.462	0.008	26
Ball balance (MABC)	0.321	n.s	26	0.420	0.016	26
Total score (MABC)	0.366	0.003	57	0.401	0.001	57
Fra ord til bilde (Reading)	0.107	n.s.	55	0.400	0.001	55
Fra bilde til ord (Reading)	0.186	n.s.	59	0.262	0.023	59
Edderkopper (Reading)	0.152	n.s.	59	0.184	n.s	59
Forståelse av ord (Reading)	0.228	0.041	59	0.146	n.s	59
Bokfinken (Reading)	0.251	0.028	59	0.226	0.043	59
Solsystemet (Reading)	0.386	0.002	59	0.263	0.022	59
Værmeldingen (Reading)	0.003	n.s.	59	0.077	n.s	59
Total score (Reading)	0.285	0.018	55	0.325	0.008	55

Note: The correlations were performed using the total sample of subjects that participated in the screening and that had been participating in all the tests, also those who were not selected for group comparisons. Two classes were tested on the MABC and reading. The scores on the individual sub tests of the MABC were available only for one of the classes; thus N for the MABC correlations is 26 while N for the Reading correlations is 59. The smaller N on one of the reading sub tests as well as the reading total score is due to missing values (i.e. some subjects had skipped one sub test and, thus, total score could not be obtained).

6.5 Discussion

This study set out to determine whether motor and reading impairments in children were related to the same or different visual deficits. The results obtained from the tests of visual functioning lead to the conclusion that the children who were motor impaired but not reading impaired were inferior to the control group only on parvocellular functioning. Those children who were poor in both motor and reading

skills were inferior in both magnocellular as well as parvocellular function compared to the normal children. However, when compared to those children who were motor impaired but not reading impaired, they were inferior only in magnocellular functioning. In as far as the tests used are valid tests of magno and parvocellular functioning, the hypothesis that magnocellular function is linked to reading impairment, while parvocellular function is linked to motor impairment and that the co-occurrence of motor and reading impairment is associated with more general visual dysfunction, is supported.

Considering the results from the present study as well as from earlier studies that have shown dyslexics to perform just as well or even better than controls on tasks thought to measure sustained (parvocellular) system (Lovegrove et al, 1986), the high correlation between reading skill and the parvo-test may seem somewhat surprising. However, it has to be remembered that correlations do not imply causality. The most obvious interpretation, therefore, is that although level of parvocellular function is associated with reading skill, the group comparisons suggest that reading difficulties do not seem to be associated with deficits in parvocellular function.

Although the present analyses suggest that motor impairment is associated with a parvocellular deficit, this does not mean that magnocellular function does not play a role in motor tasks. Because the magnocellular system is sensitive to movement, it is likely that a magnocellular deficit would lead to problems in all situations where the subject has to act in relation to a moving environment, as for example in ball games. Reading, as well as other visual tracking tasks, is dependent on saccadic eye movements. These movements activate the transient, magnocellular, channels which are sensitive to stimulus movement (Lovegrove, 1994). Therefore, magnocellular systems sensitivity to speed of movement and its activation by the saccadic eye-movements may explain the significant correlation between the visual magnocellular test and the motor sub tests Shifting Pegs and Flower Trail (as saccadic eye movements would seem to be central in both these tasks).

There are indications in the literature that the transient system is not only related to visual perception, but also to phonological skills and higher perceptual processes. For example, Lovegrove and colleagues (1988) showed that phonological recoding loaded on the same factor as the measures of transient processing. As an explanation of this relation Lovegrove (1994) has suggested that both magnocellular dysfunction and poor phonological skills might be due to an underlying timing deficit that affect

both the visual (magnocellular) as well as the auditory modality (i.e. problems with temporal processing of auditory stimuli). Therefore, it is also possible that an underlying problem with temporal processing could explain the significant correlations between the visual magnocellular test and the reading sub tests “The solar system”, “The chaffinch” and “Comprehension of words”, tasks that depend on phonological skills in reading and listening and on higher cognitive functions such as drawing inferences and understanding the meaning of words. An underlying timing deficit, like a problem in processing rapidly presented stimuli in all modalities, it is suggested (Lovegrove, 1994; Stein & Walsh, 1997), is likely to contribute to motor deficits as well and may, thus, explain why reading and motor impairment tend to co-occur.

The parvocellular system, on the other hand, is specialised at recognising shapes, which plays a role in orthographic reading. Thus, the significant correlation between the visual parvocellular test and the reading sub test, “Fra ord til bilde,” may be explained by a parvocellular influence in recognition of single words. This fits well with earlier findings that dyslexics have problems reading a whole line (more dependent on magnocellular processing) but not with the reading of single words (parvocellular processing), and it supports the notion that parvocellular dysfunction is not related to reading impairment.

With respect to motor skills, the high and significant correlations between the parvocellular test and all three balancing tasks (One board balance, Hopping in squares, Ball balance) are striking. Considering that the sustained (parvocellular) system plays a major role in central vision and, hence, the ability to focus (Lovegrove, 1994), it is not unlikely that parvocellular function may have an effect on postural skills. For example, it is easier to balance on one leg when the eyes are focused. Considering that postural skills are very central in most motor tasks, this might be part of the explanation why the poor motor skills group performed so poorly on the parvocellular test.

Provided that motor and reading impairments in subgroups of children can be related to magno- and/or parvocellular deficits this may have some implications for practice. Training may either be directed to the underlying causes, i.e. training on tasks that require magno and/or parvocellular function, or towards compensatory strategies. For example, a compensatory strategy in learning to read, for a child with a magnocellular deficit, might be to practice orthographic reading (which is thought to depend mainly on the parvocellular system). On the other hand, a child with a

parvocellular deficit might benefit more from using phonologic strategies (that are thought to depend on the magnocellular system) in reading. A compensatory strategy in the teaching of motor skills, as for example in ball catching, could be to help the learner focus on those visual cues that his visual system is capable of detecting. That such a strategy might be effective was shown in a study, albeit with normal subjects, where learners who were forced to seek additional information sources under restricted viewing conditions demonstrated greater effect than a control group on acquiring a catching skill (Bennett, Button, Kingsbury & Davids, 1999). By forcing the learners to seek additional sources of information during the restricted viewing conditions they learnt a “visual strategy” that was effective also under normal visual conditions. In the same manner it should be possible to teach visual strategies to children with different kinds of visual deficits. For example, in the task of catching a ball, if a child has a problem with picking up peripheral visual information (which might be due to poor magnocellular function) it is likely that this child would benefit from focusing on the ball (central vision) rather than relying too much on the peripheral information.

The present study supports the idea that different visual deficits are associated with motor and reading impairments in children, a parvocellular deficit linked to motor impairment and a magnocellular deficit linked to reading impairment. Further, the co-occurrence of motor and reading impairments seem to be linked to a more general visual deficit that encompasses both magnocellular and parvocellular dysfunctions.

It is possible that the visual deficits are linked to underlying variables that affect other sensory systems as well. More research needs to be done in order to investigate the relative contribution of the magno- and parvocellular systems in the reading process and their relation to motor skills. Also, the relation between the magnocellular theory and other suggested explanations to the co-occurrence of motor and reading impairments in children needs to be further investigated. With a view to intervention, research should be directed at evaluating possibilities of “repairing” the underlying deficits and of teaching compensatory strategies.

6.6 References

- American Psychiatric Association (1994). *Diagnostic and Statistical Manual of Mental disorders* (4th ed.). Washington DC: Author.
- Bennett, S., Button, C., Kingsbury, D. & Davids, K. (1999). Manipulating visual informational constraints during practice enhances the acquisition of catching skill in children. *Research Quarterly for Exercise and Sport*, 70, 220-232.
- Dewey, D. & Kaplan, B.J. (1994). Subtyping of developmental motor deficits. *Developmental Neuropsychology*, 10, 265-284.
- Fawcett, A.J. & Nicolson, R.I. (1992). Automatisation deficits in balance for dyslexic children. *Perceptual and Motor Skills*, 75, 507-529.
- Fawcett, A.J. & Nicolson, R.I. (1995). Persistent deficits in motor skill of children with dyslexia. *Journal of Motor Behavior*, 27, 235-240.
- Fawcett, A.J., Nicolson, R.I. & Dean, P. (1996). Impaired performance of children with dyslexia on a range of cerebellar tasks. *Annals of Dyslexia*, 46, 259-283.
- Hansen, P.C., Stein, J.F., Orde, S.R., Winter, J.L. & Talcott, J.B. (2001). Are dyslexics' visual deficits limited to measures of dorsal stream function? *Neuroreport*, 12, 1527-1530.
- Henderson, S. & Sugden, D. (1992). *The movement assessment battery for children*. Kent: The Psychological Corporation.
- Livingstone M, Rosen GD, Drislane F & Galaburda A (1991). Physiological evidence for a magnocellular defect in developmental dyslexia. *Proceedings of the New York Academy of Sciences*, 88, 7943-7047.
- Lovegrove, W. (1994). Visual deficits in dyslexia: evidence and implications. In A. Fawcett & R. Nicolson, *Dyslexia in children : multidisciplinary perspectives*. London : Harvester Wheatsheaf, pp 113-135.
- Lovegrove, W., Martin, F., & Slaghuis, W. (1986). A theoretical and experimental case for a residual deficit inspecific reading disability. *Cognitive Neuropsychology*, 3, 225-267.
- Lovegrove, W., McNicol, D., Martin, F., Mackenzie, B., & Pepper, K. (1988). Phonological recoding, memory processing and memory deficits in specific reading disability. In D. Vickers and P. Smith (Eds.), *Human Information Processing: Measures, mechanisms and models* (pp. 65-82). North-Holland:

Amsterdam.

- Moore, L.H., Brown, W.S., Markee, T.E., Theberge, D.C., & Zvi, J.C. (1996). Callosal transfer of finger localisation information in phonologically dyslexic adults. *Cortex*, 32, 311-322.
- Nasjonalt Læremiddelsenter (1997). Kartlegging av leseferdighet – 5. Klasse (Mapping of reading skills – 5th grade). Nasjonalt Læremiddelsenter, Postboks 8194 Dep., 0034 Oslo. Norway.
- Stein, J. & Walsh, V. (1997). To see but not to read; the magnocellular theory of dyslexia, *Trends in Neurosciences (TINS)*, 20, 147-152.
- Wolff, P.H., Melngailis, I., Obregon, M., & Bedrosian, M. (1995). Family patterns of developmental dyslexia. 2. Behavioral phenotypes. *American Journal of Medical Genetics*, 60, 494-505.

Chapter 7

GENERAL DISCUSSION AND CONCLUSIONS

7.1 Summary

The aim of the present thesis was to shed light on the relation between motor and language (vocal language as well as reading) impairments in children. As outlined in the theoretical overview in Chapter 1, the co-occurrence of language and motor impairments in children may be indirectly related, mediated by social constraints, or directly related as a result of a common underlying disorder such as, for example, a neural deficit. The present thesis is based on the latter assumption. The contention was that behavioral observations would provide clues as to what could be the underlying neural deficit. Being well aware of the fact that conclusions about neural dysfunctions best can be made on the basis of direct measures, indirect measures that provide knowledge about the relation between brain and behavior are also important in order to understand and test the validity of neuropsychological theories and, thereby, also tease out how they can be important in understanding both normal and abnormal development and learning in children. Behavioral studies can also provide ideas that in the next round can be tested using direct physiological measures.

To that end, the empirical data in the present thesis are based upon measures of functional behavior such as motor skills, vocalization and reading as output variables, while the input variables are of a proprioceptive, visual and/or auditory nature. These data are interpreted in the light of neuropsychological theories focusing, in the main, on neural structures such as the corpus callosum (as a contributing factor in observed bilateral co-ordination problems), the lateral hemispheres (may be involved in the explanation why motor problems in some cases are restricted to one side of the body), the cerebellum (which is known to be central in motor control and timing of movements), and on the magno- and parvocellular cells in the visual system (that are likely to play a role in explaining the observed visual problems). A schematic illustration of the empirical data and theoretical assumptions upon which the present thesis is based is shown in Figure 1.

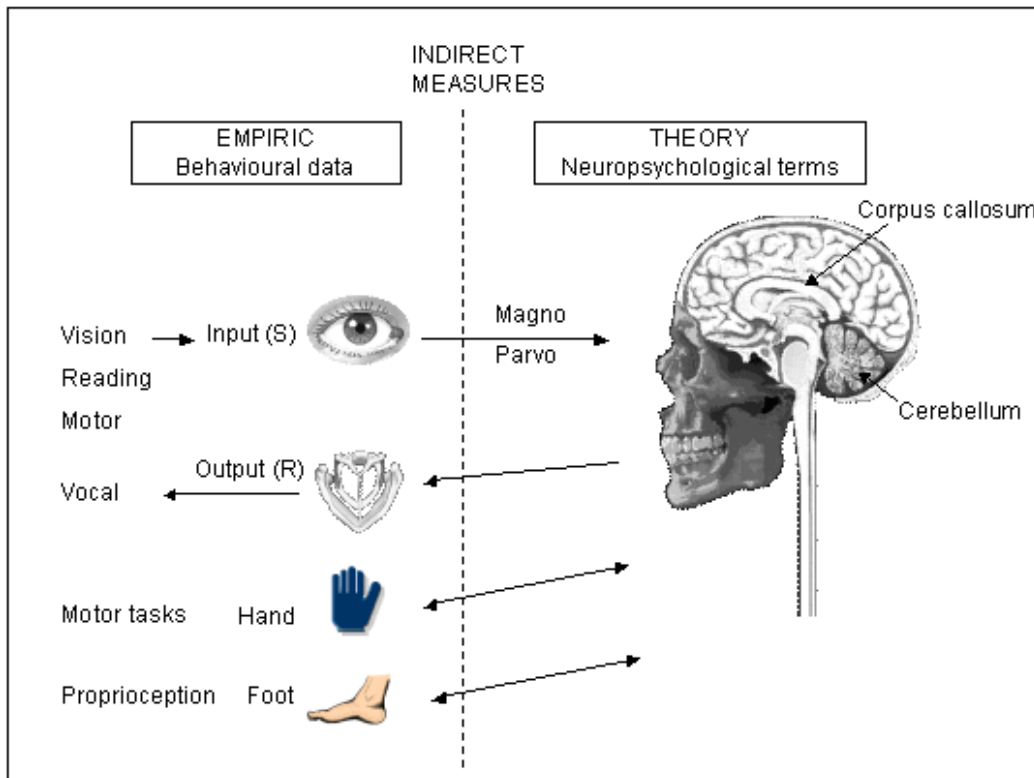


Figure 1: The figure is a schematic illustration of the empirical data (input and output variables) upon which the present thesis is based and the indirectly derived neuropsychological theoretical interpretations.

More specifically, chapter one provided a theoretical overview of direct and indirect relations between language/reading and motor impairments with emphasis on the direct relations and the different putative theoretical explanations suggested in the literature. It was concluded that a common underlying variable that gave rise to both language and motor deficit could be attributed to a developmental lag or to abnormal neural development.

Chapter two was addressed to a group of predefined language impaired children aged from 4 to 10 years old. The psycholinguistic abilities of these children were assessed by means of the Illinois Test of Psycholinguistic Abilities (ITPA) and their motor skills were assessed using the Movement Assessment Battery for Children (MABC). The quantitative analyses confirmed earlier studies in showing there to be a significant difference between the groups in overall motor performance. However, the motor problems in the language impaired group did not appear to be general but to be restricted to bimanual co-ordination, drawing and static balance. Further, qualitative

analyses revealed that the significant group differences in motor performance were attributable to only half of the language impaired children, as only 4 out of the 8 selected language impaired children could be categorized as motor impaired. These four subjects shared four communalities in their motor and language profile, namely poor performance on the MABC-subtests static balance and bimanual co-ordination, and on the ITPA subtests Visual Closure and Sound Blending. It was concluded that both the cerebellar and the inter/intra hemispheric hypotheses could provide plausible neuropsychological explanations for the co-occurrence of language and motor impairments in the selected sample.

The validity of the inter/intra hemispheric deficit hypothesis was investigated in Chapter three. The same group of language/motor impaired children as those in Chapter two together with a control group matched for age and gender carried out two sensory matching tests designed to tap inter and intra information processing abilities: hand-hand and foot-hand. The results were in support of the inter-hemispheric deficit hypothesis, suggesting that there was a problem in inter-hemispheric transfer of information from left to right. But little support was found for the intra-hemispheric deficit hypothesis. Liederman's shielding model was suggested as a plausible explanation to the problems observed in this group of children. This model is built upon the assumption that the corpus callosum fails to actively shield, or minimize, inter-hemispheric interactions between the two hemispheres when the requirement is to carry out simultaneous but independent processing.

In Chapter four the focus was on motor coordination problems *per se*. A group of 10-11 year old children with motor co-ordination problems and a control group matched on gender and age were selected on basis of the Movement Assessment Battery for Children. Spatial and temporal adjustments in eye-hand co-ordination were studied more thoroughly in these groups by means of a reaching (mainly imposed by spatial constraints) and a grasping task (mainly imposed by temporal constraints). The reaching task mainly activated the proximal proprioceptive system, while the distal proprioceptive system was activated in the grasping task. The motor impaired group was less accurate both in spatial and temporal adjustments. It was suggested that this could be due to an underlying visual and/or proprioceptive problem. Children with movement co-ordination problems may experience difficulties in catching a ball either because they are not able to interpret the visual stimuli

(spatial and temporal orientation of the ball) or because they are not able to move their hand to the desired position at the right time, due to proprioceptive insufficiency.

The validity of the visual/proprioceptive hypotheses as an explanation of the poor eye-hand co-ordination skills observed in this group of children was investigated in Chapter five. The same groups of children as those participating in the reaching and grasping experiments were compared on proprioceptive and visual tasks. Two different matching tasks, hand-hand and foot-hand, were utilized in order to measure proprioception. Visual processing was measured by means of three different computer-based psychophysical tests, designed to measure magno- and parvocellular functions. The results showed there to be no significant differences in proprioceptive skills between the two groups. However, the large and significant differences on all three visual tests, both the magnocellular as well as the parvocellular tests, were quite striking. It was concluded that this group of motor impaired children was suffering from visual processing problems, and that these problems were even more extensive than those previously observed in dyslexics. As these children were not screened for reading deficits, the results, with respect to motor impairments could have been biased by the inclusion of reading impaired children in the motor impaired group.

Chapter six was designed to determine whether the two types of visual processing deficit (magnocellular and parvocellular) were differently attributed to reading and motor impairments. Therefore, a larger group of similar aged children was screened for motor and reading skills by means of the Movement Assessment Battery for Children and a reading test respectively. Based on this screening three groups were selected: a motor impaired group without reading impairments, a group which was both motor and reading impaired and a control group with normal motor and reading skills. These three groups were compared on two visual tests, the one designed to measure magnocellular function and the one to measure parvocellular function. The results supported the hypothesis that reading and motor impairments *per se* are related to different visual processing problems, and that in those cases where motor and reading impairments co-occur, the visual problems are more extensive.

A flow diagram with an overview of the empirical studies and the tasks used in each paper is presented in Table 1.

Table 1: Flow diagram of the empirical studies. The diagram shows age-group, type of screening-test (motor or language/reading) and experimental tasks used in the respective papers. Note that the same motor screening test (MABC) has been used for all groups. Language impairment, as specified by the ITPA, has been studied with relation to the youngest age group (up to 10 years), while the focus has been on reading impairments, as identified by means of a Reading test, in the older age group (above 10 years).

Paper	Subjects: Age group	Screening		Experimental task		
		Motor screening	Language/Reading Screening	Hand-Eye coordination	Proprio-ception	Visual perception
2	5-10 years	MABC	ITPA			
3	5-9 years	MABC	ITPA		HH, FH	
4	10-11 years	MABC		Reach and grasp		
5	10-11 years	MABC			HH, FH	Magno/Parvo
6	10-11 years	MABC	Reading test			Magno/Parvo

Abbreviations: Movement Assessment Battery for Children (MABC), Illinois Test of Psycholinguistic Abilities (ITPA), Hand-Hand matching (HH), Foot-Hand matching (FH), Magnocellular visual test (Magno), Parvocellular visual test (Parvo).

7.2 Discussion

The aim of this thesis was to explore the hypothesis that underlying neuropsychological causes may explain motor co-ordination problems in children as well as certain language/reading problems. As these activities are all based on a perception-action coupling (e.g. see a ball in flight and grasp it or read a word and pronounce it), especially the question of whether there are common or unique factors behind problems in these areas is of great interest. Also the question of development and maturation is central in these problems.

So, in what sense may this thesis have contributed to the understanding of these questions? Even though some of the following is more properly regarded as speculative I will try to outline some possible implications of the thesis with the expressed purpose to trigger discussion about the topics and hopefully motivate follow up studies.

Maturation

It has been a common, but also controversial statement related to children with motor and language problems that – they would grow out of it! Parents are by teachers and

therapists, recommended not to worry about motor problems demonstrated by their young children, as the problems, it is assumed, will disappear with time.

This is a statement that may be understood in the light of this thesis. The clue is to be found in the different results for the younger children in Chapter 3 and the older children in Chapter 5. The difference being that the motor and language problems in the younger children are correlated significantly to proprioceptive measures, while no such links are found for the older children. One possible explanation for this is that the group of motor impaired children simply has changed after the age of 10-11, as a function of the maturation of the corpus callosum. With a fully matured corpus callosum, only the children with other kinds of problems are left as motor impaired children.

If this is a valid hypothesis, it is one with great implication for therapy. One should not rely on the belief that the children “automatically” will grow out of their motor or language problems unless one is certain that the problem at hand is subject to maturational change. This obviously does not seem to be the case if the problems are perceptual and not linked to maturational stage of the corpus callosum.

Another possible explanation is that the group of language/motor impaired children studied in Chapters 2 and 3 belong to a different subgroup from that of the reading and motor-impaired group in Chapter 6. Still, the indications that in some cases language and reading impairments belong to the same subgroup has to be kept in mind, as there is a tendency for children with phonological language impairment to develop dyslexia when they get old enough to learn how to read and write (Plaza, 1997).

Differentiation of causal explanations

At the outset, it was unclear what could be common or unique causes of motor and language problems in children without obvious brain damage. As outlined in Chapter 1, many options seemed reasonable. Through the findings in this thesis it might be possible to argue for a more narrow approach.

The findings suggest that subgroups may be divided across the borders of language and motor impairments, i.e. that certain kinds of language and motor impairments belong to the same subgroup. For example, in Chapter 2, a language and motor impaired subgroup with common problems in phonology, visual closure, static balance and bimanual co-ordination was separated from a group which was language

impaired only. Taking into consideration the relations between language/reading impairments and motor impairments, this means that in certain subgroups of children language, reading and motor impairments might be different sides of the same coin, originating from a common underlying neural disorder.

Magno- and parvocellular functions as related to reading and motor skills

Chapter 6 showed that motor impaired children may be divided into two subgroups depending upon whether they have related reading problems or not, and these two subgroups were shown to suffer from different kinds of visual deficits. The group, which was motor impaired but not reading impaired appeared to be deficient in parvocellular function only, while the group which was both motor and reading impaired showed deficiencies in both magno and parvocellular functions. Previous studies on dyslexic samples, where motor skills have not been assessed, have shown reading problems to be related to magnocellular dysfunctions.

The correlation table in Chapter 6 showed that magno- and parvocellular functions are related to different subcategories of motor and reading skills. The significant correlations between parvocellular function and static balance were quite striking, and are probably due to the role of the parvocellular cells in visual fixation. For example, balancing on one leg is easier when the gaze is fixated on a certain point than if it is drifting around, a technique also used by experts in balance, like line dancers and gymnasts.

Visual fixation also plays a role in reading. Another speciality of the parvocellular system is the ability to recognise shapes, which is important in orthographical reading. The ability to recognise shapes would also be of importance in grasping, when the hand has to be shaped relative to the shape of the object to be grasped. So this is an obvious possible common factor that may explain problems in both areas.

The main function of the magnocellular cells is their sensitivity to movement and their role in peripheral vision. The relation between poor magnocellular function and reading disability may be explained by the fact that the magnocellular cells play an important role in compensating for the movement created by the saccadic eye movements. If the magnocellular system is not activated by the saccadic eye movements the text would appear to “dance around”, a problem frequently reported by many dyslexics. In motor skills the magnocellular sensitivity to movement, and its

crucial role in peripheral vision, would cause problems in all situations where the subject has to act in relation to a moving environment. That may explain why many dyslexics report that they have problems in participating in ball games. Magnocellular function, therefore, may be expected to be a strong common factor in many perceptual-action problems.

Cerebellar hypothesis

In Chapter 4 it was suggested that the jerky movements demonstrated by the motor impaired children might be a sign of an underlying timing problem due to a cerebellar deficit. The same group of children also showed evidence of poor visual magnocellular function (Chapter 5). It is possible, therefore, that both the jerky movements as well as the poor performance on the visual test of magnocellular function could be related to a cerebellar deficit.

A common trait for all the tasks, reading as well as motor subtests, that correlated significantly with magnocellular function was the dependency upon fast signal processing. Lovegrove and colleagues (1988) have suggested that the deficit need not be in the magnocellular system *per se*, but in an underlying timing deficit that affects both the visual (magnocellular) as well as the auditory modality (i.e. fast temporal processing of auditory signals). Anatomically, visual input to the cerebrotocerebellum originates from the cortical targets of the magnocellular stream of the central visual pathway (Purves et al., 1997).

Implications for intervention

Based on the assumption that intervention is most effective when directed towards the source, rather than the symptoms, of a problem, the aim of the present thesis was to identify putative underlying deficiencies in motor and language impairments. When such variables are identified, intervention may be directed towards “repairing” the underlying deficits and/or towards the teaching of compensatory strategies. For example, the present thesis has shown that both motor and reading impairments are associated with visual deficits, and some suggestions are made as to how visual deficits related to the magno and parvocellular systems may contribute to different kinds of motor and reading impairments. It is believed that a specifically designed training program, or other kinds of medical treatment, directed towards one such deficient system, might contribute to reduce the underlying deficit and resulting

symptoms. Further, it is likely that this would improve the motor and reading capabilities that are dependent on this visual function. This, however, presupposes a flexibility and adaptability in the system, that normally is associated with a young system i.e., it suggests that the earlier the training/intervention takes place, the better.

Alternatively, one could teach children strategies that would compensate for their visual deficits. For example, in the task of ball catching, the child could learn to focus on visual cues that his visual system is capable of detecting, a strategy which previously has been shown to be effective (Bennett et al., 1999). If the problem is related to a magnocellular deficit (and not parvocellular) the child could be taught to focus on the ball, rather than relying too much on peripheral information (which depends on magnocellular cells). Similarly, in the task of reading, it might be useful to follow the text with the index finger, which would place more emphasis on the parvocellular system. More research remains to be done, both when it comes to the diagnosis of such “underlying” deficits and in designing and evaluating treatment programmes. However, the children's own ability to find ways of coping with their weaknesses should also not be underestimated. Such compensatory coping strategies were demonstrated in Chapter 4 where the late reaching and early hand opening movements apparently reflected strategies to compensate for their problems in visual perception and timing.

Validity of indirect measures of magno- and parvocellular functions

From measures on single cell responses in monkeys the functions of magno- and parvocellular cells have become known. Based on the knowledge that the magnocellular cells are specialised at recognising movement while the parvocellular cells are specialised at recognising shapes, psychophysical computer based visual tests have been designed. Therefore, the magnocellular task was to identify moving dots on the screen, while the parvocellular task was to recognise a pattern. However, as the measures are only indirect, one cannot be completely sure that the observed deficiencies are due to poor functioning of the magno- or parvocellular cells *per se*.

There is also a possibility that the deficit is on a higher processing level. One way to test the validity of the psychophysical magnocellular task would be to see how well it correlates with the ability to dark adaptation, which is entirely dependent upon the magnocellular cells. A way to test the validity of the parvocellular task could be to look at correlations with tasks containing coloured stimuli (a speciality of the

parvocellular system). Further validation could be done by comparing the magno- and parvocellular tests used with recordings of visual evoked potentials (more direct measures of cell responses in the visual cortex) to stimuli evoking magno- and parvocellular responses.

Suggestions for further research

This thesis has shown that focusing on the co-occurrence (and *not* co-occurrence) of language and motor impairments may be a fruitful approach for providing new insight into the etiology of language and motor impairments. However, further research is necessary before firm statements may be made. Therefore, important questions to guide future research should be: “Why do motor and language impairments co-occur in some children and not in others, are there certain kinds of language/motor impairments that tend to co-occur, and why do these particular impairments tend to co-occur?” These questions may best be answered by focusing on different subgroups of language and motor impaired children, i.e. children who are only language or motor impaired compared to those who are both language and motor impaired. A combination of quantitative and qualitative methods would seem beneficial for this purpose.

Further studies are necessary in order to pinpoint the underlying nature of the observed visual problems as related to language and motor impairments in children. The question whether these problems are due to magno- and/or parvocellular function *per se* or to some other underlying neural dysfunction needs to be answered. Also, the developmental lag hypothesis as related to the maturation of the corpus callosum should be further investigated. Longitudinal studies would seem beneficial for this purpose. With a view on intervention research should be directed at evaluating possibilities of how specific training introduced at an early stage can be used as prevention or as a tool for “repairing” the underlying deficits and of how children could benefit from learning compensatory coping strategies.

In conclusion I hope that this thesis can be a small step further into the understanding of motor and language problems. In general the findings lend more support to a visual perceptual and cerebellar understanding of the problems than a proprioceptive approach (focusing on corpus callosum and inter and intra hemispheric functions) for the older children (above 10 years), while the latter factor seems to have more explanatory power in the understanding of motor and language problems before full

maturation of the corpus callosum. Further research is needed before firm statements about these topics may be made.

7.3 References

- Bennett, S., Button, C., Kingsbury, D. & Davids, K. (1999). Manipulating visual informational constraints during practice enhances the acquisition of catching skill in children. *Research Quarterly for Exercise and Sport*, 70, 220-232.
- Lovegrove, W., McNicol, D., Martin, F., Mackenzie, B., & Pepper, K. (1988). Phonological recoding, memory processing and memory deficits in specific reading disability. In D. Vickers and P. Smith (Eds.), *Human Information Processing: Measures, mechanisms and models* (pp. 65-82). North-Holland: Amsterdam.
- Plaza, M. (1997). Phonological impairment in dyslexic children with and without early speech-language disorder. *European Journal of Disorders of Communication*, 32, 277-290.
- Purves, D., Augustine, G.J., Fitzpatrick, D., Katz, L.C., LaMantia, A.-S., & McNamara, J.O. (1997). *Neuroscience*. Sunderland, Mass.: Sinauer Associates.