Introduction

1.1 Children with a Developmental Coordination Disorder

The ability to coordinate parts of our motor system in a proper way is considered a prerequisite for skilled performance in many everyday life activities. During the course of development, children go through a process of skill acquisition in which they learn to coordinate and control their movements in an adequate way. For most children this is not a problem, although their performance is often less skilled than that of adults. However, for some children it is a problem to coordinate and control their movements adequately, resulting in less skilled or -to use a more specific characterization- ‘clumsy’ motor behavior. In the literature, these children have been referred to as ‘clumsy’ children (Gubbay, 1975), ‘poorly coordinated’ children (Johnson, 1987), or ‘physically awkward’ children (Wall et al., 1990). In this thesis, we will adopt the term Developmental Coordination Disorder (DCD), which was introduced in the ‘Diagnostic and Statistical Manual of Mental Disorders III-Revisited’ (DSM-IIIR, 1987). According to the recently published DSM-IV manual (DSM-IV, 1994), children with DCD are characterized by a poor performance in daily activities that require motor coordination that is not due to the child’s age or intellect, or caused by known neurological disorder (e.g., cerebral palsy, muscular dystrophy), and which interferes with academic achievement or activities of daily living. The prevalence of DCD has been estimated to be as high as 6% for children in the age range of 5-11 years (DSM-IV, 1994).

Although children with DCD are easily recognisable by their ‘clumsy’ and ‘uncoordinated’ behavior, research has not been very successful in pinpointing the nature of their coordination disorder. Given the complexity of the multiple subsystems involved in the organization of movements, this is not so surprising. In the last decades, DCD has been predominantly investigated from a neurobehavioral and an information processing perspective. The neurobehavioral approach has been used to explore aberrant motions (e.g., choreatiform movements) and subtypes of movement dysfunction in various subsystems that contribute to the organization of motor behavior. Classifications such as developmental dyspraxia (Gubbay,
1975; Denckla, 1984) or sensory integrative dysfunction (Ayres, 1979) stem from such an approach. The neurobehavioral approach, however, lacks a sound theory with regard to how movements are coordinated and controlled. The information processing approach, which has been applied in quite a number of DCD studies, investigates the contribution of perceptual and cognitive processes (i.e., stimulus identification, response selection, motor programming) to problems in the motor organization of movements of children with DCD, using simple tasks (e.g., reaction time; goal directed movements). Such studies have suggested that children with DCD may have a deficit in visual perception (e.g., Lord & Hulme, 1987), or kinesthetic perception (e.g., Laslo & Bairstow, 1988), or in the selection, programming, and execution of motor responses (e.g., van Dellen, 1986). Although these studies have provided insight in deficits in processes between the pick up of perceptual information and the initiation of movements, the causal relation between such deficits and deviant characteristics of the movements themselves (e.g., irregularities in movement trajectories) remain largely unclear.

However, whatever the source of the coordination disorder, it is manifested in the emergent movement, or, in other words, in the spatio-temporal organization of the movements themselves (Larkin & Hoare, 1992; see also Fox & Polatajko, 1994). In order to investigate the spatiotemporal movement organization more in detail, theories and models of motor control and coordination are needed.

In this thesis, we will apply a dynamic pattern approach to examine problems in the temporal organization of coordination patterns of children with DCD. This approach, which has been recently introduced within the field of human movement science, differs from the more traditional information processing or motor program approach in the sense that it does not consider the motor system as an hierarchically organized system. In the dynamic pattern approach, the motor system is considered a complex and dynamical system, in which coordinated movements -and disorders thereof- result from nonlinear interactions of parts of the system.

A major problem in research on motor difficulties in children with DCD is that they do not constitute a homogeneous group. The lack of homogeneity makes it difficult to identify the mechanism underlying the observed coordination disorder, and may also be responsible for inconsistent experimental findings on DCD in the literature. One way to handle this problem is to look for subtypes of DCD based on movement dysfunction. In this thesis it is suggested that coordination dynamics (see chapter 2) are an appropriate tool for identifying subtypes in DCD, because coordination dynamics can be applied to functionally different coordination systems (e.g., interlimb coordination, or coordination between a rhythmically moving limb and periodic perceptual events), and at different levels of observation (e.g., behavioral, muscular).
1.2 Timing control in DCD

In the search for the underlying mechanism(s) of DCD, it has been suggested that a deficit in timing control might be related to the motor problems of children with DCD in the sense that certain aspects of the motor programming (i.e., the sequencing and timing of motor responses) are not adequately processed (Geuze & Kalverboer, 1987; Williams, Woollacott, & Ivry, 1992). This is most clearly expressed in rhythmic coordinated movements, which is one of the action categories for which children with DCD seem to be impaired. The present thesis therefore focuses on timing control and the temporal organization of rhythmic coordinated movements following a dynamic pattern approach. In specific, we investigate the relative timing in bimanual rhythmic coordination and in unimanual rhythmic perception-action coupling.

1.3 Aim of the thesis

The aim of the present thesis is to examine the intrinsic dynamics of rhythmic coordinated actions in children with and without DCD by testing the stability of these patterns. Two basically different coordination systems are examined, namely, rhythmic interlimb coordination and rhythmic perception-action coupling (i.e., coordinating a rhythmically moving limb with periodic perceptual events). Since there is little known about the development of coordination stability in these coordination systems in childhood, the first part of the thesis focuses on age related differences in stability in children in the age range from 6 to 11 years. The second part focuses on differences in stability between a group of children with DCD and age matched controls. The research questions can be formulated as follows:
1. Are there age related differences in the stability bimanual rhythmic coordination and unimanual rhythmic perception-action patterns in school age children?
2. Are there differences between children with DCD and age matched controls in the stability of bimanual rhythmic coordination and unimanual rhythmic perception-action patterns?
3. Can we identify subtypes of children with DCD based on differences in coordination stability?

1.4 Outline of the thesis

The outline of the thesis is as follows. In chapter 2, the main contents of the dynamic pattern approach to rhythmic coordinated movements are summarized. Chapters 3 to 6 concern experimental work. In chapters 3 and 4, age related differences in the stability of rhythmic movements are examined, using a cross-sectional design. Chapter 3 focuses on bimanual
rhythmic tapping, and describes age related differences in stability, as well as practise induced effects on the critical frequency of antiphase coordination patterns. Chapter 4 focuses on age related differences in the ability to synchronize or syncopate unimanual rhythmic tapping to periodic auditory events. In chapters 5 and 6, differences in stability between children with DCD and matched controls are examined. Chapter 5 focuses on single and bimanual rhythmic finger movements, and investigates the relationship between limit cycle stability at the level of individual limb movements and relative phase stability at the level of interlimb coordination. Further, it discusses the results in terms of the underlying timing mechanisms involved. In chapter 6, the stability of visuomanual rhythmic coordination is examined and compared to the bimanual coordination stability results presented in chapter 5. Further, coordination stability measures are related to the neurodevelopmental status of the children with DCD. Finally, the identification of subtypes of DCD based on differences in coordination stability in functionally different coordination systems is discussed. A summary of the main findings and conclusions are presented in chapter 7.