Development of Movement Co-ordination in Children

Applications in the Fields of Ergonomics, Health Sciences and Sport

Edited by
Geert Savelsbergh, Keith Davids,
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Preface

The co-ordination of movement at a simple and complex level is one of the key tasks of human development. In their daily activities children demonstrate many different patterns of co-ordinated movement and throughout childhood learn and develop many different skills to perform a variety of tasks. The chapters brought together in this book discuss some of these skills; both very basic skills such as walking, hitting, throwing, catching, kicking and reaching for objects, and more complex skills such as learning to ride a bicycle, crossing the road, using a spoon to eat, drawing and writing.

One of the best known definitions of movement co-ordination is that of the Russian physiologist, Nikolai Bernstein. He saw co-ordination as the mastering of redundant degrees of freedom into a controllable system (Bernstein, 1967, p.127). 'Degrees of freedom' refers to all the possible movements of all the sub-components of the motor apparatus of the human body; for example, joints. There are several different perspectives on how we solve the problem of achieving this mastery and different researchers adopt different perspectives in order to examine the task at hand. These perspectives are discussed in the introductory chapter to the book. Five major paradigms are described: the neural-maturation perspective; information-processing theories; the ecological psychological or direct perception approach; dynamic systems theory; and constraint-led or co-ordinative structure theory. The last three are the more recent approaches and therefore the majority of chapters have been written with these frameworks in mind.

The individual chapters represent the latest research and thinking in the fields of ergonomics, health science and sport and provide the reader with new insights into both theory and practical applications. In all these areas there is an increasing awareness of the importance of understanding the development of movement co-ordination and how this might affect, for example, the design of equipment, the enhancement of everyday activities, rehabilitation practices, or training and practice in sport skills.

For these reasons, we think the book will be of great interest to researchers, teachers, coaches, therapists and students in various fields, including sport sciences, kinesiology, physical education, ergonomics, human movement sciences, health sciences, physical therapy and developmental psychology.

The contributors to the book come from Australia, new Zealand, Canada, Europe and the United States of America. They include those with established reputations and young authors who are just beginning to make their mark. Together, they bring a wide-ranging perspective to bear on this rich and expanding field of study, and we thank them for their contribution to this project.

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Reference

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1 Theoretical perspectives on the development of movement co-ordination in children

Geert Savelsbergh, Keith Davids, John van der Kamp and Simon J. Bennett

1. Introduction

In a great diversity of daily activities children demonstrate skilled and well co-ordinated movement behaviour. To reach such levels of performance and flexibility takes years of learning and development. This book deals with the development of movement co-ordination of daily activities, like throwing, writing, reaching, walking, catching, kicking and cycling. An important characteristic of skilled performance is the ability to adjust the movement pattern to the (changing) circumstances of the environment.

Nikolai Bernstein (1967) formulated one of the central issues in understanding the development of motor co-ordination: the 'degrees of freedom' problem. The degrees of freedom problem refers to the possible movements of all the components (e.g. muscles, tendons, joints etc.) of the motor apparatus of the human body. Bernstein realised that the non-linear nature of the interactions among these different components of the human body makes their separate regulation impossible and inferred that to be able to control all these components, or degrees of freedom, these movements have to be co-ordinated. Co-ordination, therefore, is the process of mastering the redundant degrees of freedom into a controllable system (see Bernstein, 1967, p. 127).

The issue of mastering the degrees of freedom has been approached in different ways. In this chapter we will discuss five major perspectives, that is, the neural-maturation perspective; information-processing theories, the ecological psychological approach, dynamic systems theory and the constraint theory.

2. Neural-maturation perspective

Achievements in motor behaviour, such as grasping, sitting, crawling and walking, were believed to occur at a predetermined age. This resulted in a perspective of motor development as a rather rigid and gradual unfolding of postures and movements that was mainly attributed to the general process of maturation of the central nervous system. Co-ordinative movement patterns emerge in an orderly genetic sequence; that is, in cephalo-to-caudal and central-to-distal sequences. By an increasing cortical control over lower reflexes the movement patterns became more co-ordinated. For instance Peiper (1963) argued that basic motor skills, like walking, were not learned by experience but simply a result of cerebral maturation. In his book he used the example of a 6-month-old girl with a bilateral congenital hip dislocation. She was put into a plaster cast until 18 months and was unable to stand. At 18 months the cast was replaced by a half cast, and one day later, she started to walk (Peiper ,1963, p. 233). This example illustrates nicely the core idea of this approach.

The major contribution to the understanding of the development of movement co-ordination was the establishment of the so-called 'milestones' of development by Gesell (e.g. Gesell and Amatruda, 1945) and McGraw (1943). Gesell and Amatruda (1945, p. 20) suggested that 'maturation is the net sum of the gene effects operating in a self-limited time cycle'. In the same time period, McGraw argued that motor development is possible if 'a certain amount of neural maturation must take place before any function can be modified by specific stimulation'. This is not a strict neural-maturation point of view and leaves room for environmental influence. In the more recent constraint-led approach, the maturation of the nervous system can be considered as one of the constraints

3. Information-processing approach

The basic idea of the information-processing perspective is that it divides the cognitive system (e.g. the central nervous system) into components and determines the way in which these components process and transform information. In this respect the computer is often used as a model for the brain. The concept of memory is important as the approach emphasises representations for the storage of information. Differences between novices and experts are attributed to differences in stored knowledge with respect to the task at hand, and the associated processing activities. When a skill is learned the suggestion is that the person acquires and stores increasingly complex knowledge about that skill. The differences between experts and novices result from the use of different strategies and informational cues; that is, an expert acquires a variety of problem-solving strategies. From this perspective, children are initially regarded as novices, who then 'move' to expert status as they develop. Thus, development involves improving the strategies for encoding and manipulating information. Two types of model influence and dominate the development of movement co-ordination: the closed- and open-loop models.

The closed- and open-loop models (e.g. Adams, 1971; Miller *et al.*, 1960) had their heydays in the 1960s and 1970s. In these models, feedback loops for error corrections or a feed-forward mechanism, respectively, were invoked for explaining the control and co-ordination of the motor behaviour, but were not often subjected to developmental questions. However, there are a few noticeable exceptions such as Bruner (1970) and Connolly (1970), who promoted closed-loop models. Development was considered as learning to sequence (or programme) the different parts of an action. For instance, when grasping a toy, the infant has to learn that (s)he should reach first. However, at that time, most developmental researchers were primarily concerned with constructing motor tests and gathering normative data (e.g. Cratty, 1970; Wickstrom, 1977; Williams, 1983). As a result most studies were descriptive and a theoretical framework to explain the origin of new motor behaviours was missing, which of course was not very stimulating for the study of motor development (Netelenbos and Koops, 1988; Wade, 1977).

4. The coupling of perception and action: a direct perception perspective

Gibson's (1979) ecological psychology approach to perception is also known as the direct perception perspective. The word 'direct' refers to the fact that objects, places and events in the environment can be perceived without the need for cognitive mediation to make perception meaningful, such as in the information-processing approach. Information in the environment is not static in time and space, but specifies events, places and objects. The child has to learn to pick up and select the appropriate information, not how to interpret or construct meaningful perception from stimuli. Therefore, whenever an infant or child has learned to (actively) pick up the information, (s)he perceives events and not some kind of discrete stimulus. This concept of information is closely related to the concept of affordances.

An affordance expresses the relation between perceiving and acting:

> The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill. The verb to afford is found in the dictionary, but the noun affordance is not. I have made it up. I mean by it something that refers to both the environment and the animal in a way that no existing term does. It implies the complementarity of the animal and the environment.
>
> (Gibson, 1979, p. 127)

Affordances relate to possibilities for action for an organism in a particular environment. Therefore, they relate to the perceiver's own potential action system. For example, for an actor who wants to climb stairs, the co-ordination pattern is specified by the ratio between the tread height (action space) and the actor's leg length (metric of the actor) (Warren, 1984). In more general terms, perceiving and acting are guided by body-scaled ratios, which should be similar over individual differences in body dimensions. Henceforth, developmental changes due to physical growth should not affect the perception of affordances; that is, during development children should remain tuned to similar body-scaled ratios without the need for new learning or reorganisation of the action system (Pufall and Dunbar, 1992; Van der Kamp, Savelsbergh and Davis, 1998).

Within this perspective, Van der Kamp *et al.* (1998) examined how children aged 5, 7 and 9 years reach, grasp and lift cardboard cubes of different sizes (ranging from 2.2 to 16.2 cm in diameter). Recordings were analysed and scored qualitatively for the percentage occurrence of one-handed grasps. The findings showed that the older the child, the higher the occurrence of one-handed grasps (37 per cent, 46 per cent, and 55 per cent for the 5-, 7- and 9-year-olds respectively). Moreover, the older the child, the larger the cubes that were predominantly taken with one hand. From a direct perception approach, it is hypothesised that the detected differences in grasping behaviour between the age groups are due to the increase of hand size with age. Therefore, the observed differences in prehension should disappear when hand size is taken into account. When hand size was scaled to cube size, differences in prehension between the three age groups disappeared and the shift from one-handed to two-handed grasping occurred at the same body-scale ratio between cube size and hand span for all three age groups. In sum, the children perceived the affordances for action.

According to E. Gibson (1988) affordances have to be discovered with the aid of the perceptual systems and exploratory behaviour. Michaels and Carello (1981) stress the active nature of the exploratory behaviour:

> Exploration (attention) is not an unconscious shifting-through and subsequent rejection of most inputs: It is directed control of what will be detected.
>
> (Michaels and Carello, 1981, p. 70)

In the eyes of these authors exploration is an active and directed process which reveals affordances, as illustrated by an experiment carried out by Karen Adolph and co-workers (Adolph *et al.*, 1993). In their study walkers and crawlers were encouraged to ascend and descend a sloping walkway of 10, 20, 30 and 40 degrees. The findings showed a relation between the exploratory activities and locomotion ability. For instance, on descending trials walkers switched from walking to sliding. Also they touched and hesitated most before descending 10- and 20-degree slopes and explored alternative means for descent by testing different sliding positions before leaving the platform. Crawlers hesitated most before descending 30- and 40-degree slopes and did not test alternative sliding positions. The experiment demonstrated the relation between infant locomotion capability, the perception of affordances (traversable by walking or not) and the exploratory activity.

The theory of direct perception offers insights into developmental perceptual–motor processes by studying learning in the context of development. What is learned is the detection of affordances; that is, what action possibilities the environment affords for the child. In this respect, learning to move and to co-ordinate one's actions involves learning to select the appropriate information sources. Moreover, this learning depends on the present action capabilities of the child. These action capabilities may improve by the maturation of the central nervous system, the sensitivity to certain information sources, the growth of body dimensions and the ability to couple information and movements. It is through the active and directed exploration of the environment with his/her own action system that the child learns to detect affordances, pick up the relevant information, and to couple the information to movements.

5. Dynamic systems approach to the development of co-ordination

Within the last decade, there has been an increase in empirical evidence that developmental processes are not smooth and monotonic, but can be characterised by phenomena such as discontinuities, transitions, instabilities, and regressions (Savelsbergh *et al.*, 1999; Van Geert, 1999; Van der Maas, 1993; Wimmers *et al.*, 1998). These phenomena are characteristic of non-linear dynamical processes. The aim of the dynamic systems approach is to characterise spatio-temporal and functional patterns of motor behaviour in terms of their stability properties by formalising the time-evolution of relevant variables into dynamical equations of motion. Stationary, stable states or patterns of activity, as well as abrupt transitions between different states accompanied by loss of stability (induced by changes in external conditions), have been successfully modelled in this way (Kelso, 1995).

The perspective portrays co-ordination as a process that constrains the potentially free variables of a system into a behavioural unit. A collective variable (order parameter) is the parameter that captures the observed behaviour (co-ordination pattern), while a control parameter is the parameter that leads the system through different co-ordination patterns. Within this approach, the behavioural pattern is regarded as a stable collective state attained by the system under certain constraints (boundary conditions) and informational settings (Zanone *et al.*, 1993). When the control parameter passes through a critical point, a co-ordination pattern that was stable becomes unstable, causing a sudden discrete transition to a qualitatively different, stable co-ordination pattern. Such a change appears without any prescription from outside but is acquired by the system itself, i.e. through self-organisation.

From this perspective the development of co-ordination is also seen as a complex, evolving dynamic process. Developmental systems are self-organising in that new behavioural forms emerge in a non-linear fashion at the macroscopic level (e.g. reaching) as a result of interactions between subsystems at more microscopic levels of organisation (e.g. between neurons or between muscles and joints). In this context, self-organisation is defined as the system's ability to acquire a new spatial, temporal or functional structure by itself (i.e. without any prescription of this structure from the outside). The ability of a system to organise itself is most salient when a qualitative change in order occurs. Such a transition is called a non-equilibrium phase transition.

Tools provided by a dynamic systems approach make it possible to detect qualitative changes (i.e. phase transitions) which are induced by quantitative changes in one or more control parameters. The control parameter is not the cause of the change, although its manipulation is instrumental in creating the new order (e.g. walking, reaching and grasping). It controls in the sense of leading the system through its respective states of equilibrium (that is, from one phase to the next); for instance, from reaching to reaching and grasping. A discontinuous phase transition involves an abrupt shift from one stable configuration of behaviour to another without stable intermediate states.

Developmental phases such as reaching, grasping, sitting, crawling etc. can be viewed as stable, preferred configurations of behaviour. When perturbed, the child