The importance of grounded assessments and interventions: Towards a new framework for Developmental Coordination Disorder

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Declaration

I hereby confirm that this work is my individual effort. All quotations and sources of information have been properly acknowledged in the manuscript. All papers (I – V) included in the present thesis followed the ethical standards of the World Medical Association's Declaration of Helsinki concerning Ethical Principles of Medical Research involving Human Subjects and in accordance with the Swedish rules on ethics.

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Natura enim non nisi parendo vinciyur
(Nature to be commanded must be obeyed)
Francis Bacon (1620)

This Thesis is dedicated to all persistent children and adults, their parents and spouses, who made the studies possible. It is also dedicated with love to my dear wife and companion Irene

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Abstract

The overarching purpose of this Thesis is to evaluate assessments and interventions for sensorimotor therapy according to the method Retraining for Balance. The purpose of the first study (**Paper I)** was to compile instruments based on the 46 diagnostic tools according to the method Retraining for Balance (RB) in order to be able to analyse previously collected data and thereby examine whether future studies would be of interest. Results showed that further studies were of interest and that RB could be a complement to existing treatment methods for Developmental Coordination Disorder (DCD). The aim of the second study (**Paper II**) was to gain increased understanding of the effects of sensorimotor therapy on the physical and psychological development of children and young people when using RB. As the qualitative analyses proceeded three themes emerged, (a) Introductions, (b) Regressions and (c) Transformations. The process involved in RB can thus be described as a flow in which Introductions, Regressions and Transformations jointly pushed the individual toward an increased physical and psychological maturity. The main purpose of study three (**Paper III**) was to investigate if a group of primary reflexes are to be found in adults showing symptoms of sensorimotor disorders, and, if so, is it possible to integrate these reflexes through sensorimotor therapy (SMT). Results showed that the same diagnostic instruments and treatment methods can be used for both children and adults with sensorimotor difficulties and that the difficulties can't be out grown. The aims of study four (**Paper IV**) were to (a) compare healthy children in terms of sensorimotor maturity to untreated children diagnosed with DCD and (b) compare healthy children to diagnosed children following completed treatment with sensorimotor therapy. The results showed, in accordance with the first hypothesis of the study that the Norm group performed better on all sensorimotor tests as compared to the untreated children from the DCD group, with the exception of an audiometric test where both groups performed at the same level. Results also showed, after controls for natural maturing effects, that the participants from the DCD group, after sensorimotor therapy did catch up with the healthy children, which led to that the second hypothesis was rejected. In **Paper V**, which was an invited Focused Review, our central theme was the importance of grounded assessments and interventions in regard to DCD. The paper had two aims, (a) to follow-up **Paper III** and (b) to fill a gap in literature regarding assessments and interventions of DCD. Our previous results had indicated that sensorimotor problems could be treated within all age groups through the method RB. It was therefore concluded that the importance of primary reflex suppression and vestibular stimulation as well as a combination of top-down and bottom-up approaches have to be considered in order to develop effective methods for assessment and intervention of DCD. The method RB underlines not only the importance of gravity and its influence on the vestibular system but also the importance of parental (or spouse) guidance during training. Therefore a Brain Body World Interaction (BBWI) perspective including both a vertical connection (*i.e.,* interactions between the person and gravity) and a horizontal connection (*i.e.,* the person who socializes, learns and acts in the world) is proposed as a starting point for a new theoretical framework regarding DCD.

Keywords: *Brain Body World Interaction; Developmental Coordination Disorder; Horizontal Connection; Primary Reflexes; Regression; Remission; Sensorimotor Therapy; Transformation; Vertical Connection; Vestibular Stimulation.*

This thesis is based on the following five research papers, which will be referred to in the text by their Roman numerals:

I Niklasson, M., Niklasson, I., & Norlander, T. (2009). Sensorimotor therapy: Using stereotypic movements and vestibular stimulation to increase sensorimotor proficiency of children with attentional and motor difficulties. *Perceptual and Motor Skills*, *108,* 643-669.

II Niklasson, M., Niklasson, I., & Norlander, T. (2010). Sensorimotor therapy: Physical and Psychological regressions contribute to an improved kinesthetic and vestibular capacity in children and adolescents with motor difficulties and concentration problems. *Social Behavior and Personality*, *38,* 327-346.

III Niklasson M., Rasmussen P., Niklasson I., & Norlander T. (2015). Adults with sensorimotor disorders: Enhanced physiological and psychological development following specific sensorimotor training. *Frontiers in Psychology, 6:* 480.

IV Niklasson M., Norlander T., Niklasson I., & Rasmussen P. (2017). Catching-up: Children with developmental coordination disorder compared to healthy children before and after sensorimotor therapy. *PLoS ONE, 12,* (10):e0186126.

V Niklasson M., Rasmussen P., Niklasson I., & Norlander T. (2018). Developmental coordination disorder: The importance of grounded assessments and interventions. *Frontiers in Psychology, 9:* 2409.

CONTENTS

Abbreviations

ADHD	Attention Deficit Hyperactivity Disorder
ATNR	Asymmetrical Tonic Neck Reflex
BBWI	Brain-Body-World Interaction
CAT	Conceptual Act Theory
CO-OP	Cognitive Orientation to daily Occupational Performance
DCD	Developmental Coordination Disorder
DSM-5	Diagnostic and Statistical Manual of Mental Disorders, fifth edition
DSP	Dynamic Systems Perspective
GMM	Gross Motor Milestones
INPP	Institute for Neuro-Physiological Psychology
KOT	Keystone Ophthalmic Telebinocular
KVDM	Kinesthetic-Vestibular Development Model
KVS	Keystone Visual Skills test
NSS	Neurological Soft Signs
NTT	Neural Task Training
PSQ	Parents Symptom Questionnaire
RB	Retraining for Balance
PA	Physical Activity
PE	Physical Education
RB-A	Retraining for Balance – Audiometric test
RB-OB	Retraining for Balance - Orientation and Balance test
RB-P	Retraining for Balance – Physiological test
RFT	Reasons for Training
SMT	Sensorimotor Therapy
TRS	Teacher Rating Scale

1. INTRODUCTION

1.1 Theoretical perspectives

1.1.1 Introduction

The term Developmental Coordination Disorder (DCD) was coined at a consensus meeting at the University of Western Ontario, Canada in 1994 and defined as a chronic and usually permanent condition (Ahonen et al., 2004) largely equivalent to what was previously called 'Clumsy Child Syndrome', referring to children whose motor development is delayed regardless of age, intellect or whether neurological causes are evident. Between 5 and 9 % of all school children are estimated to be affected (Cairney et al., 2006). What is now labelled DCD was previously recognized (Pennington, 2000) under different names such as 'motor deficiency', 'congenital maladroitness', and 'Minimal Brain Dysfunction'. As a motor skills disorder (American Psychiatric Association, 1994, 2013) the main features for DCD in younger children is clumsiness, often in combination with delayed motor milestones, difficulties buttoning clothes, zipping pants and tying shoelaces. Manifestations among older children are difficulties in printing or writing, playing ball, assembling puzzles and building models. DSM-5 (American Psychiatric Association, 2013) defines DCD accordingly: "Developmental Coordination Disorder is diagnosed only if the impairment in motor skills significantly interferes with the performance of, or participation in, daily activities in family, social, school, or community life" or "if the coordination difficulties are not better explained by visual impairment or attribute to a neurological condition" (p.75).

Although DCD has a most specific and common comorbidity in ADHD it remains a 'black sheep', which seldom is mentioned in intervention and assessment manuals (Gillberg, 2003, 2017) and is still today regarded as a 'hidden problem' (Caçola, 2016). With extended knowledge about DCD and its persistence throughout life as well as knowledge about its different comorbidities (Rasmussen & Gillberg, 2000), research regarding detection (Mahoney et al., 2004), assessment instruments (Schoemaker & Wilson, 2015), interventions in early childhood (Kirby, 2004; Wilson, 2004), and in schools (Norlander et al., 2005) ought to be priority not the least due to a high risk of additional problems such as depression and anxiety (Caçola, 2016).

1.1.2 An overview of the articles in the dissertation

This Thesis contains five articles, all of which are ultimately based on the clinical experience at the Vestibularis Clinic. In order to scientifically evaluate whether or not the method Retraining for Balance (RB) could be of help for children with sensorimotor difficulties, **Paper I** focused on the development of appropriate test instruments. By similar reasons it became momentous to acquire a deeper understanding of the recurrent psychological regressions, frequently observed during training. In **Paper II** a model, the "kinesthetic-vestibular model of development" (KVMD), was identified, described and then validated through a 3-point scale. As the sensorimotor therapy at the Clinic became more established and known an increased interest from adults expressing their wish for treatment became obvious but so far RB had not been used on adults. Therefore it was considered to be of importance to use the knowledge, which had been gained from our two previous studies, to investigate whether the method could be of help even for adults. That investigation took place in **Paper III**, which simultaneously gave further psychometric confirmation to previously

developed instruments as well as to the KVDM. Despite or rather due to the hitherto described efforts it became increasingly disturbing that the instruments hadn't been used on healthy children in order to enable a comparison with children diagnosed with DCD, before and after therapy according to RB. However, the shortcoming was rectified in **Paper IV** in which, concurrently, the question of 'remission' was raised, a notion that should be scrutinized in further studies. In conjunction with the publication of **Paper III** the authors were awarded by the journal Frontiers in Psychology and invited to write a Commentary, a Focused Review, which finally became **Paper V.** In this paper the different themes that had been elaborated in **Paper I** to **IV** was discussed. It was also concluded that in order to develop effective methods for assessment and intervention of DCD over the life span the importance of primary reflex suppression and vestibular stimulation as well as a combination of bottom-up and top-down approaches have to be considered. With the results from the five studies here included, I intend to elaborate the material further in the Discussion section through some relevant questions.

1.1.3 The Reflex

A reflex can be defined as a mechanically determined and adaptive response when a sense organ is stimulated. For the function of the human body, reflex activity is fundamental (Rider, 1972). The history behind the concept 'reflex' is long and sometimes complicated, since both its theoretical and practical meaning has changed both over time and depending on research field. However, among psychologists, the concept is recognized as a basic aspect within physiological psychology and has been given a certain historical status (Clarke & Jacyna, 1987).

1.1.4 The Reflex – both somatic and psychic

Although the papillary reflex was observed already by Galen (A.D 129-199) and the word 'reflex' was used by Jean Astruc (1684-1766) (Flugel, 1933) the concept did not reach widespread recognition until the noun 'the reflex' was used in a biological and purely mechanical and functional sense by Marshall Hall in 1833 (Liddell, 1960; Clarke & Jacyna, 1987). Through his research on decapitated animals Hall had observed that by proper stimulation certain kinds of bodily movements were elicited with the help of the spinal cord and the peripheral nerves. These movements were independent of the brain and had therefore another character compared to voluntary and conscious movements (Flugel, 1933; Jeannerod, 1985). Hall's findings were to be reshaped and further developed by different researchers (*e.g.* Swazey, 1969) over the coming years but might have reached its peak around the turn of the century through research made by Charles Scott Sherrington (1857-1952). Sherrington made essential neurological discoveries where the reflex arc was a fundamental part of a goal directed and integrated nervous system (Jeannerod, 1985; Liddell, 1960; Swazey, 1969).

During the second half of the nineteenth century, theory and practice concerning 'the reflex' had a great influence on research in both physiology and psychology not only in England and France but also in German speaking countries and in Russia (Guenther, 2015; Jeannerod, 1985) and it was not unusual that physiological findings were interpreted into a philosophical framework nor that philosophy influenced physiology. One example is the British philosopher Herbert Spencer (1820-1903) who was impressed by experiments on 'the reflex' and outlined in his book 'The principles of psychology' (1855) a hierarchical CNS where the complexity increases with each new stage. At the lowest stage he put 'the reflex', which was given the role of a psychic act i.e., the psyche was described as a bundle of

reflexes. If these reflexes where frequently repeated by instincts they would become transmitted to following generations by heredity. Influences from Spencer were later to be found in writings by the neurologist John Hughlings Jackson (1835-1911) and by Ivan Setchenov (1829-1905), acknowledged as 'the father of Russian physiology and psychology' (Jeannerod, 1985). Although more than a generation apart Setchenov's research would later have impact on research made by another Russian, Nikolai Bernstein (1896-1966) who laid the foundations for a theory of motor control and contemporary biomechanics of human movement (Feigenberg, 2004). Bernstein's theories about a nervous system that is learning by its interaction with the world (*e.g.* Thelen, 1998) have had great influence on present day theory of child development where motivation is stressed as a prerequisite for the development of new motor skills (*e.g.* Goldfield & Wolff, 2004; Santrock, 2011).

1.1.5 Infant reflexes - a perspective

According to DSM-5 (American Psychiatric Association, 2013) some children diagnosed with DCD show Neurological Soft Signs (NSS) and Ayd jr (2000) wrote that NSS are used to describe neurological aberrations not believed to constitute well-defined neurological disturbances. NSS are difficult to localize, they might sometimes be considered as reflecting a diffuse brain dysfunction, but are nonetheless frequent among youths with hyperactivity and emotional disorders. The use of 'Soft Signs', both as a concept and as a diagnostic tool, was dismissed by Ingram (1973) as 'soft thinking'. However, according to Mitchell (2003), NSS are of importance because they are rarely present in healthy controls. There is no standard list of NSS but the concept includes retained primitive reflexes, a deficit in sensory integration and subtle deficits in the sequencing of complex motor functions. Children diagnosed with DCD (Polatajko, 1999) don't show any clear-cut evidence of neuropathology or neurological 'hard' signs but might show 'soft' neurological signs.
Infants are born with certain so-called primitive reflexes all of which are supposed to be suppressed under normal circumstances during the first year of life (Rider, 1972).

One of the first to document the development of infant reflexes from birth and beyond, through experience and learning was William Thierry Preyer (1882/1923) not only a physiologist but also a pioneer in the science of child psychology. Preyer (1841-1897) was after his death credited by Ernst Moro (1918) for being first to describe and document the movement pattern that later should be named the Moro reflex (Dennis, 1935).

Neonates (Illingworth, 1987) are equipped with about 70 brainstem mediated primitive reflexes, some of which are closely connected to the vestibular system. To begin with, these reflexes are like a 'survival kit' and they are easy to elicit. During the first year of life (Capute & Accardo, 1991) as the nervous system matures and voluntary motor activity emerges they become more difficult to elicit. When primitive reflexes are inhibited during the first year of life, postural (body righting) reactions (Capute & Accardo, 1991; Morrison, 1985) as well as gross motor milestones such as rolling, creeping (locomotion in prone), and crawling (quadrupedal locomotion) appear. Gross motor milestones generally emerge during the 6th to 12th month. This is also one of the intervals when the vestibular system is most sensitive and receptive to stimulation (Ornitz, 1983). During the period when the child is creeping and crawling (Maurer & Maurer, 1989) it is also very likely that a more mature sense of balance develops.

These early reflexes (Crutchfield & Barnes, 1993) were traditionally called 'primitive' either because they were thought of as not being persistent throughout life or because the infant's brain was considered primitive, underdeveloped, and deficient in comparison to an

adult's brain (Touwen, 1984). There are, however, controversies surrounding the concept. First, Touwen (1984) argued that neither the concept 'primitive' nor the concept 'reflex' are appropriate since neither is the infant's brain primitive nor does pure stereotyped reflexes occur. McPhillips and associates (2000) preferred to use the concept 'primary reflexes' while French authors such as Mehler and Dupoux (1994) used the concept 'archaic'. Second, there is a controversy as to whether, 'the reflexes' persist throughout life or not. Paulsen and Gottlieb (1968) pointed out that when a primitive reflex emerged from a certain background, foetal reflex responses may reappear whenever higher controls weakened, a view shared by Teitelbaum (1967) for whom it was obvious that the reflexes remain within the nervous system. Ayres (1973) concluded that the degree of mastery over the reflexes is a reflection of the maturity of the nervous system.

A possible regression to lower level brain activity when higher levels are impaired, resulting in primitive motor behaviour, was suggested by Bergström (1963). Jacobs and Gossman (1980) investigated certain primitive reflexes and found them active in healthy adults. So did van Boxtel and associates (2006) who found that the prevalence increased with age, but there was no support regarding their presence as markers of cognitive recession in individuals ageing normally. Touwen (1984) on the other hand, considered the morphological difference between the adult's brain and the infant's brain. Emphasizing their different functions, he argued that the adult's ageing brain and the infant's healthy brain cannot possibly display identical mechanisms.

1.1.6 The Reflex – pathological or normal

Traditionally, aberrant primary reflexes have been connected to pathological conditions. This interpretation goes back to research by Magnus and de Klejn in 1913 and their identification of the tonic neck reflex in a 'brain-damaged' child (Rider, 1972). Somewhat later Gordon (1929) held that, if the Moro reflex persists above the age of six months it was a sign of brain injury. Likewise, Rider (1972) wrote that according to many researchers a persistent Asymmetrical Tonic Neck Reflex (ATNR) beyond the first six months of life might be a sign of an arrested development or a mental retardation and should be taken seriously. Motor skills problems are serious threats to both physiological and psychological health (Caçola, 2016; Faught et al., 2005) but so far, the role of aberrant primary reflexes, underdeveloped postural reactions, and delayed gross motor milestones beyond infancy have been overlooked in developmental research and the same holds true for the role of the possible 'sixth sense', the vestibular system (Besnard et al., 2015; Fuchs, 2018; Rine, 2009) with its importance for sensory integration (Ayres, 1973).

1.1.7 Possible precursors to the modern understanding of the vestibular system

Ever since Antiquity scholars have, in different ways, described and named both sensory coherence and its possible location. Aristotle (ca. 384-322 B.C) discussed the senses and concluded that there could not be more than five. Yet, he argued, each sense is not enough to explain the totality of sensory experience and proposed the perceptual phenomena 'common sensibles' including movement, rest, figure, number and magnitude, all of which are common to all senses (Aristotle, 1992). This 'sense', which Aristotle also called 'the inner sense' or 'the first sense', had some sort of sovereignty over the other senses and made it possible to experience perceptions and sensations at the same time (Frede, 1995). During the Middle Ages Aristotle's work was translated and the term 'sensus communis' (common sensibles) (Howes, 2009) was used and discussed within Greek, Arabic and Latin scholastic

traditions. The most distinguished physician in ancient Persia was Ibn Sina (in Latin called Avicenna, 980-1037), who knew the work of Aristotle, stated that 'sensus communis' was located in the forepart of the brain's front ventricle. All impressions, which were imprinted on the five senses, were transmitted to 'sensus communis' (Finger, 1994).

Although 'The Enlightenment' in the 18:th century primarily was the 'Age of Reason' it was also an 'Age of Sensibility', a time during which the idea of 'common sense' and 'sensorium commune' was reinvented with a start in French scientific and philosophical circles (Howes, 2009; Riskin, 2009). In his book 'Essays on human understanding' (1765/1997), which was completed in 1705 but published only after his death, the lawyer by training Gottfried Wilhelm Leibnitz (1646-1716) unfolded a theory of 'petit perceptions' and 'apperceptions' where 'petit perceptions' were described as perceptions, which do not reach a conscious level while 'apperceptions' do. In 1833, Hall presented his theory on reflex action, which many physiologists at the time found too mechanistic and restrictive. In Hall's theory 'true sensations' played no part. However, the German anatomist and physiologist Johannes Müller (1801-1858) did not agree and extended Hall's theory by including the brain. Thereby did he not only include sensation but he also broke down the distinction between lower and higher neural structures which dominated Hall's model. Müller stated that the stimulation of a sensory spinal nerve first evokes action in the nerve which, then goes to the spinal cord and the sensation will be conscious if it from there can reach the 'sensorium commune' (Clarke & Jacyna, 1987; Guenther, 2015).

1.1.8 Identifying the vestibular system

The late 18th and early 19th centuries were obviously very active and fruitful years for physiological research (Finger, 1994; Wade, 2009). Observations gave empirical support for a separation of a muscle sense from touch. The British neurologist Henry Charlton Bastian (1837-1915) believed that information, necessary for the brain's coordination of motor acts, was provided by the muscles. In 1880 he coined the term 'kinaesthetic' a concept replaced in 1906 by Sherrington's term 'proprioceptive'. Although both giddiness and vertigo (Wade, 2009) had been well known phenomena, described mostly in medical terms since ancient times, it took a long time for science to connect the sensations to the vestibular system. By 1765, Robert Whytt included vertigo among the symptoms caused by nervous diseases. Antonio Scarpa (1752-1832) described in 1789 the inner ear and the labyrinth, including the connections between the ampulla and the semicircular canals. Today the vestibular ganglion carries his name, the Scarpa ganglion (Desai & Dua, 2014).

In 1803, Bell discussed diseases of the inner ear documenting that an inflammation around the auditory nerve also gave an increased sensitivity for vertigo and concluded that little was known about diseases of the labyrinth. The gross anatomy of the labyrinth was known but its function was not understood. Through the interest in vertigo, the vestibular system was obviously investigated indirectly. William Charles Wells (1757-1817) who carried out research on post rotational vertigo and nystagmus was later to be recognized as the first who suggested a connection between the vestibular sense and behaviour. Theoretically, he also understood that some neurological system must register the body's position in relation to gravity but he never came up with an answer. The answer was provided in the 20th century when the electron microscope was invented and scientists were able to identify hair cells in the cochlea and later in the vestibular system. It was not until around 1960 that modern physiology got interested in the importance of combining sensations (Berthoz, 2000). Not the least through the research by the neurologist Wilder Penfield (1891-1976), is it well known

today that the vestibular cortex, situated at the junction of the temporal and parietal cortices and fundamental for self-coherence, is where vestibular information is received. It is therefore most likely that the vestibular system is a contributing factor when it comes to establishing coherence among different senses (Berthoz, 2012).

1.1.9 The vestibular system and its response to the gravitational force

The vestibular system can easily be seen purely anatomically, as just what it is, a part of the inner ear, physiologically responsible for balance, the detection of movement and closely connected to hearing but not recognized as one of our basic senses. It is, however, different from other senses not least because experiences after stimulation are not specifically located, which they are with other senses. The gravitational force (hereafter gravity) (Niklasson, 2013) is not only ever present on Planet Earth, it is also of absolute importance for all aspects of function of the nervous system. Throughout life and through response from the vestibular system and its sensory receptors this unchanging force is the most reliable source of energy for neural activity (Hydén, 1961; Stanley-Jones & Stanley Jones, 1960). The first scientific evidence that the early development of the vestibular system is dependent upon gravitational stimulus was provided by a study on pregnant rats flown on the Space Shuttle. The rats, developed in space, had a limited sense of balance after delivery on earth. The study showed that the vestibular system needs gravity to mature correctly (Ronca & Alberts, 2000).

1.1.10 The vestibular system and human motor development

Appearing not later than nine weeks after conception, the vestibular nuclei are functional by the eleventh week (Humphrey, 1965; Piontelli, 2015). At about the 21st week, aside from the interoceptive sensory receptors (sensory receptors in the walls of the thoracic, abdominal, and pelvic viscera), the vestibular system is the only sensory system that is mature (Robbins, 1977; Larsen, 1993). Although developed this early, some authors believe that the system is inhibited during prenatal life (Windle, 1971; Prechtl, 1984). Others like Odent (1986) and Restak (1979) claimed that the foetus, floating, is constantly stimulated by the mother's movements and registers its first perceptions through the vestibular system. It is because of this early maturation that the vestibular system is so important for brain development (Piontelli, 2015). Any factor that disturbs its function will also influence further formation of the nervous system as a whole (Klosovskii, 1963). In favor of the proposition that the foetus reacts to the gravitational force (Hubbard & Wright, 1984; Eliot, 2000) is the turning of its head into the head-down position weeks or days before birth. During infancy the vestibular system is very responsive, reaching a peak between 6 and 12 months (*e.g.* Ornitz, 1983; Piontelli, 2015) a period which coincide with the development of belly-crawling, creeping on hands and knees and the child learning to walk (Capute & Accardo, 1991). Through crawling and creeping the infant will develop its sense for both directionality and space and gain the knowledge that objects are fixed points (Maurer & Maurer, 1989).

One of the first to study the psychological implications of the vestibular systems was Paul Schilder who observed that organic changes in the vestibular system did not only affect body attitudes. Changes were also reflected in psychic structures (*e.g.* Schwartz, 1981) influencing perception and consciousness. Schilder concluded that these findings could open for further studies of the vestibular system and its relation to both neuroses and psychoses (1942/1971). According to Ayres and Robbins (2005) the foundation for interpersonal relationships is a 'gravitational security', which is more primal than the relationship between mother and child.

Myrtle McGraw and Arnold Gesell made their major contributions to theories of motor development in the 1930s and 1940s. Both of them held the beliefs that children acquire motor skills through neural and that biological maturation and that motor skills are predetermined. McGraw also believed in a cortical inhibition of reflex-based movements while Gesell's opinion was that there were factors such as heredity that limited motor behaviour (Tupper & Sondell, 2004). Their theories had differences and similarities but they agreed on the importance of the infant's ability to defy gravity in order to develop (Gesell, 1945/1988; McGraw, 1945/1989). Among psychologists research in the field of motor development waned in the years between the 1950s until the1980s. However, in the 1980s research in motor development gained new interest not the least due to new technologies and research methods. Theories about neural maturation and hierarchical models lost their status and gave way for theories emphasizing the contribution of perceptual information, peripheral factors and the importance of learning in order to get movement control. These new theories were influenced by contemporary research in dynamic systems and by research from the Russian physiologist Nicholai Bernstein (Adolph et al., 2003). Bernstein's research, which was rather unknown in West at the time, caught the interest of the American developmental psychologist Esther Thelen who expanded the theories into a dynamic systems approach to development. The approach emerged basically from theories of perception-action and had and still has impact not only on the conceptualisation of early sensorimotor development (Thelen & Bates, 2003; Thelen & Smith, 2006) but also on present day recommendations for interventions concerning DCD (Blank et al., 2019).

1.1.11 Interventions – past and present

Through history some children have suffered from diseases or malnutrition and acquired brain injuries while other have been victims of environmental factors, such as abandon, contributing to indecent and wild behaviour. Others were in fact mentally retard by birth. The fate many of them shared was, for better or worse, institutionalisation (Nissen, 2005). The written history of interventions for those by then regarded as mentally limited is said to have started in 1799 with the physician and educator Jean-Marc Gastard Itard (1775-1838). Itard's work was continued by one of his medical students, Edouard Séguin (1812-1880). Influenced by the utopian socialist Count de Saint-Simon, Séguin believed that educating the mentally disabled was a step toward a better society (The Séguin physiological school, 1905/2017). Like his teacher, Séguin rejected the notion that mental retardation was incurable and practiced sense training and muscle training for the benefit of his patients (Anastasi & Urbina, 2007; Humphrey, 1962) and claimed that a child's sensory system must be mature before he/she could be taught to read and write (The Séguin physiological school, 1905). Séguin held that the mental and physical structures of normal developing humans as well as of feeble-minded are the results of an interaction between environmental conditions and heredity. Influences from the environment begin in utero and an arrested development can be traced as far back as the third month after gestation to be continued during the neonatal period (Séguin, 1907/2009).

Therefore it is important to be observant of a child's condition and start training at the right time (Séguin, 1907/2009; Humphrey, 1962). Such ideas continued to be influential in the US between the wars and became a driving force when it came to prevent behaviour disturbances among children. Books such as 'The pre-school child and his posture' (Richardson & Johnson Hearn, 1930), were written by psychiatrists and educators in order to give advice for detection and training of motor functions (Bromberg, 1982). Still today, the

methods used for testing and training mentally disabled children in sensory discrimination and motor control have their origin in Séguin's work (Anastasi & Urbina, 2007) and in no small way Maria Montessori's work was also influenced by him (Humphrey, 1962).

Recently Blank and colleges (2019) stated that children diagnosed with DCD should receive treatment in order to be able to handle ordinary life and previously Hillier (2007) concluded, after a systematic review, that an intervention as such is better than none. However, so far no 'gold standard' for neither assessment and nor interventions of DCD have been established although several approaches have been used (Blank et al., 2019; Smits-Engelsman et al., 2012). Over the years, approaches to interventions evolved within the fields of physiotherapy, medicine (*e.g.* medication), occupational therapy, education (*e.g.* physical education, instructions for teachers and parents) and diet. The approaches were labelled mainly as either process-oriented or task-oriented. The hypothesis for process-oriented or bottom-up approaches, were that skills performance are enhanced by the improvement of body functions such as sensory integration and kinaesthetic training. On the other hand, for task-oriented or top-down approaches the focus was on learning the motor performance itself. Examples are 'the Cognitive Orientation to daily Occupational Performance' (CO-OP) and 'Neural Task Training' (NTT) (Smits-Engelsman et al., 2012).

In the early years of DCD research, studies were mostly unshared process-oriented i.e. focused only on the improvement of structure and body function and reducing impairment. However, in recent years such studies have come to include also reports of a task-oriented character such as participation and activity level. A similar development has been noted in task-oriented studies where reports of impairment reduction and changes at the level of structure and body function have been added. In order to meet this change, the different approaches to intervention for DCD have been re-grouped into three new categories (1) body function and structure oriented with the aim at improving identified body functions supposed to cause suspected underling motor problems (2) activity-oriented with the aim at designing an activity which will improve the performance of the activity in question (3) participation-oriented with the aim at designing an activity which will improve participation in the activity in question in order to influence the everyday life situation. The first category was earlier known as including process-oriented approaches while the other two were known to be task-oriented. Presently, published data give evidence enough for recommendations to use CO-OP and NTT as DCD interventions (Blank et al., 2019).

1.2 Background of the present thesis

1.2.1 Introduction – how it all started

Although teachings in child development, physiology and anatomy were intensive at the School of Physical Education in Örebro, Sweden in the 1970s, education in sensorimotor training per se was scarce. During my first years as a teacher in Physical Education (PE) I experienced some under-achieving children in each class and tried to adapt my teaching to their abilities but I did nothing else. However, right from the beginning my intention was to educate my pupils. I regarded PE to be as important as any other subject and wanted to develop their 'Physical literacy'. By then the concept did not exist, only recently was it brought to the agenda by Margaret Whitehead (2001) and has since got different connotations depending on circumstances although the present definition is "Physical literacy can be

described as the motivation, confidence, physical competence, knowledge and understanding to value and take responsibility for engagement in physical activities for life" (IPLA, 2017). To me at the time, it had the meaning of giving my pupils a basic motor education in order to create a lifelong interest in physical activity. Rather soon I realized that it was through teacher education I had the best chance to influence. In the early 1980s I was appointed as senior teacher at the Teacher Training College in Kalmar, Sweden.

At the time the interest in a possible connection between motor ability and cognitive development had started to grow. Therefore it was suggested that teachings in children's motor development should be part of my subject. Also at the time William Cruickshank (1981) suggested a novel perspective for teacher training and proposed the 'Neuroeducator'. Parts of his extensive requirements were incorporated in my teachings. I had the privilege to get to know and to study with the Danish physiotherapist Britta Holle. Her book 'Motor development in children' (1981) became together with Jean Ayres' book 'Sensory integration and learning disorders' (1973) my prime theoretical foundation. Holle had also developed the 'Motor and Perceptual Development Test', which I was taught to use and I found special interest in the parts concerning reflexes and motor milestones. Teachers at local schools became more observant on sensorimotor difficulties among their pupils and after consulting their parents I was frequently asked to do assessments and programs for intervention. The work was successful and led in 1987 to a grant financed pilot study where I together with a colleague skilled in statistics evaluated the effect of a short reflex inhibition program (Niklasson & Hector, 1989). The result was promising and we suggested an extension of the study, which unfortunately never came true. However, the Head of the Department at the College considered continuing studies and evaluation of sensorimotor training as important. Not the least did he understand that increased knowledge would be beneficial for the students in their teacher training. In 1989 a pilot project was established within the department of teacher training at the University College in Kalmar. It was decided to name it Vestibularis.

1.2.2 Early experiences from the Institute for Neuro-Physiological Psychology (INPP)

I was expected to share my time between teaching and performing assessments and interventions, which finally became a too heavy burden to me. Therefore my wife Irene, also a PE-teacher by training, and Katarina Olsson, pre-school teacher, were employed part time to help me out. At a meeting Britta Holle advised me to continue to use her test as a template but look further for something that could suit our purpose even better. Already in the late 1970s I had heard about the British psychologist Peter Blythe, PhD, through friends who had met him and they told me about a book of his (Blythe & McGlown, 1979). However, at the time I paid it no notice. Dr Blythe had in 1975 founded the Institute for Neuro-Physiological Psychology (INPP) in Chester, UK and two years later a Swedish branch opened in Göteborg (Blythe, 1990). At the 2nd International Conference of Neurological Dysfunction held in Stockholm in 1988 and sponsored by the Swedish branch of INPP, Dr Blythe were one of the speakers together with, among others, Britta Holle and William Cruickshank. Dr Blythe's speech caught me and I was introduced to him. One thing led to another and in early 1989 I attended my first conference at INPP in Chester to learn more. Vestibularis was not yet established so my trip was paid for by a grant from the 'Red Cross' in Kalmar. In late 1989 Dr Blythe returned to Sweden to give a weekend seminar and the three of us applied. The title was 'Children's motor and perceptual development' and we should get to know more about 'primitive reflexes', the vestibular system', and much more. We should also be advised of how to put together a program for remediation. Luckily all three of us were present. We were heavy loaded with information and coming back home again it took us quite a while to put

things together. All new input from that weekend constitutes the start of what later came to be the method 'Retraining for Balance'.

Over the coming years we were frequent participants at both INPP-conferences and supervisions in the UK as well as in other countries. At Vestibularis in Kalmar we developed our skills further through continued practice. We had many children in training. Although we had been given a thorough theoretical background to the training the influence from INPP and Dr Blythe concerned more of the practical parts. We learned that the intervention program was based on a replication construct where each reflex had a purpose, which had to be fulfilled. The inhibition, transformation and modification of basic reflexes followed a certain pattern and a sequence, which was replicable at any age. Further, as mentioned by Thelen (1979), babies make during their first year of life certain stereotyped movements. Similar movements, studied and interpreted by Blythe (1990, 2009), not only facilitated the inhibition of the appropriate reflex but also subsequently released a proper postural reaction.

1.2.3 The development of Retraining for Balance – methods

In the early 1990s, the INPP- guidelines for how to carry out assessments (Goddard, 1990) and how to use exercises were strictly mechanical and linear, which meant that during assessment when certain immaturities, i.e., primitive reflexes, were identified certain remedial exercises from the intervention program were supposed to be used in a 'goal directed' way. From this followed that some children went through training using just a few exercises while others had to use more exercises and the duration and content became rather different from child to child. Vestibularis was not satisfied with the results achieved whilst working in this way. We had noticed that some exercises seemed more powerful than others and this inspired the attempt to create a more harmonious totality between the different movements. An important part for the continuity during training had come to be the playful complementary exercises.

One reason why we wanted to bring structure and coherence was that we had experienced the emergence of different physiological and psychological regressions when certain exercises and vestibular stimulation were used. It had been mentioned from INPP that regressions could occur temporarily with some clients (Blythe & McGlown, 1979 p. 83), later mentioned also by Goddard (2002), but when we slowed the pace of the movements we saw regressions frequently. Kris (1952) had described a 'regression in the service of the ego', a regression where the ego itself is in charge, a phenomenon not mentioned by INPP. We were later able to show (**Paper II**) that when an exercise was used long enough the regressions faded and physiological and/or psychological behaviour seemed to be transformed to a more mature level. Regression and progression (Loewald, 1978, 1981; Werner, 1957) are complementary and of great importance concerning organization both at the psychological level and of physical development (McGraw, 1935/1995). Instead of breaking the apparent 'flow' by being too mechanical, Vestibularis aimed at creating a smooth succession of exercises, thereby achieving a maximal 'squeeze' from each one. Vestibularis came to view and understand the significance of regressions (Bergström, 1963, 1964, 1969) from a developmental point of view.

A further reason for the modifications undertaken by Vestibularis was that vestibular stimulation seemed to be effective with all clients when used as a complement to foetal and neonatal movements. This view was not shared by INPP as Goddard (1990) wrote that vestibular stimulation could be used when nothing else worked. Vestibularis' modification or

rather re-construction was first named *'Education in Balance'* (Niklasson, Niklasson, & Bergström, 1999, 2007) but this was later changed to *'Retraining for Balance'* (**Paper I**) and aimed at being a method with a common start and end and with a sense of cohesion between exercises. In order to assess a client's proficiency in terms of primary reflexes, postural reactions, gross motor milestones and vestibular ability sensorimotor (physiological) diagnostic procedures were performed. Several of those diagnostic tools were selected from the manual 'Towards development re-education' (Field & Blythe, 1989) while others came from various sources (*e.g.* Capute et al., 1978; Fiorentino, 1981) or were developed at Vestibularis (Niklasson & Niklasson, 1999a, 1999b, 2007a, 2007b). In order to gain additional knowledge about clients' sensorimotor development, diagnostic tools for evaluation of audiometric- (Johansen, 1993) and visual (Burman, 1977) proficiencies were added.

1.2.4 Retraining for Balance – instruments

As described above Vestibularis came to develop a rather extensive clinical practice not only in the vicinity but also nationally. Torsten Norlander, at the time professor in Experimental Psychology at Karlstad University, had heard about the training at Vestibularis and invited me to give a lecture at a PhD-student seminar. My lecture caught his interest so after the seminar he invited me for a personal conversation where he claimed that I ought to study psychology. I was flattered and we agreed on distance studies with the possibility to be examined exclusively by Professor Norlander. Such an arrangement would suit my situation well not the least because the long distance between Kalmar and Karlstad. However, writing an essay at C-level (Bachelor level) was mandatory but Professor Norlander promised to supervise me, which solved the problem. My plan was that the essay should aim at compiling psychometrically tested instruments based on certain exercises and diagnostic procedures used at Vestibularis. The essay was approved and we decided to recast it to a manuscript, which later became an article (**Paper I**). The essay on D-level (Masters level), which was completed in a corresponding way, was a qualitative study with the purpose to gain further knowledge about the presence of regressions among clients (**Paper II**). My intention was then to complete my studies with a PhLic exam. Therefore I enrolled the program and according to the rules an assistant supervisor was demanded. To my delight Associate Professor Peder Rasmussen, who I had met already in the early 1990s, an experienced child neurologist at the Sahlgrenska University Hospital in Göteborg agreed to help me.

By the time for my PhLic exam Professor Norlander was offered a position as a professor in Medical Psychology at Evidens University College in Göteborg with an affiliation to Karolinska Institutet, Solna. Professor Norlander subsequently accepted the new position and for me five years of academic studies in combination with clinical commitments at home had been laborious so at that time I had to concentrate on Vestibularis. Since 1998 the work at Vestibularis was partly structured by a Quality Management System according to SS-EN ISO 9001, which especially stressed the importance of continuous evaluation. In order for Vestibularis to be able to continue with high-class development, a new contact with Professor Norlander and Associate Professor Rasmussen was taken. When Professor Norlander a couple of years later suggested me to apply for a PhD by published work retrospective I found the suggestion very interesting. In this way, I got in touch with Professor Jerome Carson (University of Bolton) who kindly undertook the assignment to be my Director of Studies and who, since, has given me valuable instructions while compiling my Critical Commentary.

Retraining for Balance – Physiological test (RB-P)

In **Paper I** were 41 diagnostic tools, each assessed on a 5-degee scale (0 to 4), grouped into six different dimensions: (a) Primary reflexes-vestibular stimulation (13 items), Primary reflexes-tactile stimulation (3 items), (c) Postural reactions (11 items), (d) Gross motor milestones (4 items), (e) Eye movements (6 items), (f) Sports-related gross motor skills (4 items). An index was computed for each dimension by multiplying the mean by 10, yielding a sub-scale with anchors of 0: No deviation and 40: Significant deviation from normal performance. A Cronbach alpha performed with the six sub-scales gave an estimate of 0.72. The sub-scales were then summed into a total value for the physiological test (RB-P). Also in **Paper I** some indications of concurrent validity were given since ratings of RB-P were significantly correlated with scores on RB-OB, RB-A, and with the Keystone Visual Skills test.

Retraining for Balance - Orientation and Balance test (RB-OB)

In **Paper I** there were also five diagnostic tools, each assessed on a 2-point scale (0 – 1) grouped into three categories and thereby constituted this test, first referred to as 'RB-O', subsequently in later studies as 'RB-OB'. The three categories were: (a) standing balance, (b) vestibular function and (c) body-space perception. A mean was computed for the results in each category and then the categories were summed. Although test scales were not ideal for analyses of homogeneity Cronbach alpha was 0.61. The RB-O scores correlated significantly with both RB-P, RB-A, and with the Keystone Visual Skills test.

Retraining for Balance - Audiometric test (RB-A)

This audiometric test, based on a technique developed by Johansen (1993), used the clinical diagnostic audiometer DA 74 (Danaplex, Copenhagen, Denmark). **Paper I** focused on the auditory preference in binaural pure tone audiometry and therefore a new scale (RB-A) was constructed in order to measure whether the particular participant had a right or left ear preference or whether preference was lacking. The scale spanned 0–200, on which values below 100 indicated left-ear dominance, and values above 100 indicated right-ear dominance. Right ear dominance was supposed to facilitate a more rapid processing of speech sounds (Sininger & Cone-Wesson, 2004). The test's rationale, namely the importance of right ear-dominance, had been validated by Tallal and associates (1993) as well as by Okamoto and associates (2007).

Keystone Visual Skills test (KVS)

This is a visual skills test (Burman, 1977) related to vestibular function, which has 15 test cards measuring simultaneous perception, eye coordination, stereovision, as well as the effective acuity during resting accommodation at different distances. The test cards were shown to participants who stated what they saw and responses yielded a maximum of 66 points. The test's rationale concerning relations between vision and vestibular function had previously been validated (Wenzel, 1978; Braswell & Rine, 2006).

The Kinesthetic-Vestibular Development Model (KVDM)

A qualitative study (**Paper II**) indicated that the sensorimotor therapy according to Retraining for Balance could be described as a development curve, the Kinesthetic-Vestibular Developmental Model (KVDM), where the motion exercises push the process forward and create recurrent regressions. The regressive phases were accompanied by positive phases of development where setbacks were transformed into successes. The KVDM results were rated on a 3-point scale (a) "doubtful or poor adjustment" (only one regressive phase and a few phases of transformation), (b) "good adjustment" (two regressive phases but the main

tendency of the model had to be present), (c) "very good adjustment" (three Regressive phases and four phases of transformation). The results from the qualitative investigation were validated through comparisons with 224 children whom had also completed the therapy (**Paper II**). This was corroborated when a group of adults were compared with a norm group of 398 treated children (**Paper III**).

Reasons for Training (RFT)

RFT is a questionnaire (Bergström et al., 1999) designed to assess the satisfaction of the children's parents. The parents indicated their child's problems in order of severity. At the end of the therapy the parents rated how much they thought each problem had changed on a 4-point scale with anchors of 0: No positive change, 1: Little positive change, 2: Quite some positive change, 3: Great positive change. The 4-point scale was validated (**Paper I**) through comparisons with Parent Symptom Questionnaire.

Parents Symptom Questionnaire (PSQ)

Conners´ test for parents of children with attentional problems was used (Conners, 1990; Goyette et al., 1978). The Swedish version (Gillberg, 1991) consists of 10 statements with a special focus on attentional variables, which may indicate whether or not the child has problems in the area of ADHD. It yields a composite measure and three subscales: (a) Behavioural problems, (b) Impulsivity/Hyperactivity, and (c) Inattention. Each statement was checked by the parents at the start of the training program, and at the completion on a four-point scale (0 = "not at all true", 1 = "somewhat true", 2 = "quite true", 3 = "definitely true"), where "0" indicates no problem and "3" a very major problem.

Teacher Rating Scale (TRS)

Conners´ test for teachers (Conners, 1990; Goyette et al., 1978). The Swedish version (Janols & von Knorring, 1991) consists of 27 statements and yields a summary measure and four subscales: (a) Behavioural problems, b) Impulsivity/Hyperactivity, c) Problems of Concentration, and d) Inattention. Each statement was checked by the teachers at the start of the training program, and at the completion on the same kind of four-point scales as the Parents Symptom Questionnaire.

1.2.5 Clinical procedures

The children vised the Vestibularis Clinic together with their parents. Typically, the parents had heard about the therapy from other parents, from preschool or school advisors, or from School Health Care. Before deciding to start therapy an introductory call was always made on telephone when the parents were informed about the layout and the cost of the training. How to finance therapy was entirely up to the applicant but fees were mainly paid, totally or in part, (a) privately, (b) by the Community Health Service, (c) by the children's school or by the adult's employer, or (d) through a foundation. The parents were informed that they did not have to sign up for the whole program. A decision to either continue or to stop was taken at each visit. The parents were also told about the importance of the training being performed by themselves and their child, for about 15 minutes daily, at home. The clinical procedures followed a schedule that can be summarized as follows.

Prior to the first visit parents were sent a simple questionnaire about their child's level of development and maturity, the questionnaire Reasons for Training, and a contract of mutual agreement. In the contract between Vestibularis and the parents, it was stated what the parents were expected to do for the therapy to be as effective as possible. In order to avoid

confounding data the contract also stated that there should be no medication during the program without notification to the staff of Vestibularis. Therapy could be resumed after medication or when the effects of the medication had been assessed. The contract was signed by the parents and by the staff of Vestibularis, and each part received a copy.

Once in the assessment room, the child and his/her parents are were informed about the tests. The child was told that a break could be taken during testing and he/she could even quit without giving a reason. Similarly the child and parents were informed that they could discontinue their participation without providing a reason. A copy of Conners' Parent Symptom Questionnaire and Teacher Rating Scale were given to the parents to be returned completed at the second visit. Participants completed the Physiological Test and the Orientation and Balance Test, which required about 1.5 h. Scores were recorded and participants were informed about the results.

A decision on further training was made and instructions for the home training were given. All participants began with the same exercises but as therapy progressed the training would become more individually tailored. At the second visit the first audiometric tests were carried out. Based on the results a custom made audiocassette or CD was produced from especially composed music. The item was then to be provided at the third visit along with an instruction on how and when to listen for 10 minutes per day. Re-testing would occur at regular intervals during therapy. Also at the third visit the first visual skills test were carried out. Regarding the sensorimotor training all subsequent visits followed the same pattern i.e., appropriate sensorimotor testing was performed and the child and parents described and showed how the training had been performed at home. A new program was then introduced. At the second to last visit, Conners' Teacher Rating Scale and Parent Symptom Questionnaire were given to the parents for completion on return at the last visit, during which RB-P an RB-OB also were completed and the parents filled out the Reasons for Training. For further information about the different tests used during the therapy, see section 1.2.4.

2. THE PRESENT INVESTIGATION

2.1 Introduction

The present investigation was made possible because the Quality Management System according to SS-EN ISO 9001 has been used at the Vestibularis clinic since 1999. Presently the version SS-EN ISO 9001:2015 is in use (Cianfrani & West, 2016). Within the standards of the quality system, training according to the method as well as how files are archived is controlled. All papers (**I – V**) included in the present thesis followed the ethical standards of the World Medical Association's Declaration of Helsinki concerning Ethical Principles of Medical Research involving Human Subjects and in accordance with the Swedish rules on ethics.

2.2 **Paper I.** Sensorimotor therapy: Using stereotypic movements and vestibular stimulation to increase sensorimotor proficiency of children with attentional and motor difficulties

2.2.1 Aim

The purpose was to compile instruments based on the 46 diagnostic tools according to the method Retraining for Balance in order to be able to analyse previously collected data and thereby examine whether future studies would be of interest.

2.2.2 Design

The treatment period was on average close to 3 years, and the children practiced about 15 min. per day while supervised by their parents. Throughout therapy, training was checked by visits to Vestibularis at intervals of 8 weeks. Therapy began and ended with a test battery. The children were divided in three groups, according to Piaget, based on their age at start of the project: a younger group of 51 boys and 14 girls (M = 6.2 yr., SD = 2.0); a middle group, 73 boys and 18 girls, (M = 9.0 yr., SD = 0.8); and a group of somewhat older children of 57 boys and 19 girls, (M = 12.3 yr., SD = 1.7).

2.2.3 Instruments

The instruments listed below were used (for details see section 1.2.4):
Retraining for Balance – Physiological test (RB-P)
Retraining for Balance - Orientation and Balance test (RB-OB)
Retraining for Balance - Audiometric test (RB-A)
Reasons for Training (RFT)
Teacher Rating Scale (TRS)
Parents Symptom Questionnaire (PSQ)
[Keystone Visual Skills Test (KVS) was used for concurrent validation of other sensorimotor tests administrated in **Paper I**].

2.2.4 Procedure

The procedure followed the same schedule as described in section 1.2.5. In **Paper I** only children who did not receive medication were included.

2.2.5 Statistics

Three-way mixed Pillais' MANOVAs were conducted with Treatment (before-after) as within–subjects factor and Age group (younger, middle, older) and Sex (boys, girls) as between-subjects factors for the following tests: Physiological test (RB-P), Teacher Rating Scale (TRS), and Parent Symptom Questionnaire (PSQ). Three-way mixed ANOVAs were conducted with Treatment (before-after) as within–subjects factor and Age group (younger, middle, older) and Sex (boys, girls) as between-subjects factors for the Orientation and Balance test (RB-OB) and the Audiometric test (RB-A), The questionnaire Reasons for Training (RT) was evaluated with help of descriptive statistics in order to determine to what extent the parents experienced the sensory motor therapy as beneficial.

2.2.6 Results

The results showed significant improvements on various sensorimotor tasks in all age groups as indicated by the RB-P, RB-O and RB-A tests. There was also a proficiency effect of biological development, which was evident in older children performing better than the middle and younger groups on the RB-P and RB-O, but not evident on RB-A. Furthermore, scores on the Teacher Rating Scale and the Parent Symptom Questionnaire indicated that the children in all age groups displayed significant improvement following treatment. Older children were rated as less hyperactive but more inattentive on the Teacher Rating Scale. Sex differences were found only in three instances on the RB-P. Boys performed better on the Gross motor milestones, whereas girls did better on Eye movements and Sports-related gross motor skills. Concerning Reasons for Training the distribution of the parents assessments was as follows: "Great positive change" (35.3%), "Quite some positive change" (51.7%), "Little positive change" (6.5%) and "No positive change" (1.3%). Twelve parents (5.2%) did not complete the questionnaire.

2.3 **Paper II**. Sensorimotor therapy: Physical and psychological regressions contribute to an improved kinesthetic and vestibular capacity in children and adolescents with motor difficulties and concentration problems

2.3.1 Aim

The aim of this qualitative study was to gain increased understanding of the effects of sensorimotor therapy on the physical and psychological development of children and young people when using the method Retraining for Balance.

2.3.2 Design

A cohort of 232 children and adolescents completed therapy in accordance with the method Retraining for Balance (see **Paper I**). At each visit children and their parents reported on the results of the home program and meticulous notes were kept. In this way, records were created with personal flow charts describing the experiences of the training of each participant as well as the perception of the training by the parents.

2.3.3 Procedure

In order to gain a more thorough understanding 8 cases from the cohort were randomly selected. The empirical data consisted of the records containing the flow charts and the notes from each return visit. The parents' reports were of significance because the children sometimes found it difficult to verbalize their experiences.

2.3.4 Processing the data

The Empirical Phenomenological Psychological Method (EPP-method) devised by Karlsson (1995) was used in processing the data. The method consisted of a multi-stage analysis, including techniques for dividing texts into smaller, so called, "meaning units" (MU). This division was not based on grammatical rules, but entirely on content which the researcher discovered and where there was a suitable shift of meaning. The analysis yielded 1.019 transformed meaning units that in turn generated 29 categories. Finally, the material was transformed from "situated structures" into general themes or typological structures.

2.3.5 Results

Three themes emerged, each of which consisted several categories: (a) The Introduction of various sensorimotor exercises, (b) Regressions in terms of a return to earlier behaviour, (c) Transformations in terms of positive development and change. The three themes emerged regularly throughout the entire study, and together they formed what was termed as "the kinesthetic-vestibular developmental model". The process involved in Retraining for Balance might be described as a flow in which 16 Introductions, 3 periods of Regression, and 4 periods of Transformations jointly pushed the individual toward an increased physical and psychological maturity.

The records of the 8 participants were compared to the records of the remaining 224 children and adolescents from **Paper I**. Two of the authors independently rated all records vis-á-vis the "kinesthetic-vestibular model of development" according to a 3-point scale (for details on KVDM see section 1.2.2). The results, which were noticeably alike, were then compared and agreed on. The results indicated that 63% of the children and adolescents exhibited a "very good adjustment" to the kinesthetic model whereas 32% of the records were judged to show a "good adjustment" to the model. Only 5% of the records were judged to show a "doubtful or poor adjustment" to the model.

2.4 **Paper III.** Adults with sensorimotor disorders: Enhanced physiological and psychological development following specific sensorimotor training

2.4.1 Aim

The main purpose of this study was to investigate if a group of primary reflexes are to be found in adults showing symptoms of sensorimotor disorders, and, if so, is it possible to integrate these reflexes through sensorimotor therapy (SMT).

2.4.2 Design

This study comprised of 14 adults and 100 youngsters all of whom had completed sensorimotor therapy (SMT) according to the method Retraining for Balance. The adult group consisted of 13 women and 1 man with an average age of 35.21 years (*SD* = 10.73) while a reference group of youngsters included 28 girls and 72 boys with an average age of 12.44 years (*SD* = 1.57). Both groups indicated similar primary reasons for carrying out therapy i.e., sensorimotor problems often in combination with attention difficulties, reading difficulties, sensitivity for stress and agony.

2.4.3 Instruments

The instruments listed below were used (for details see section 1.2.4):
Retraining for Balance – Physiological test (RB-P)
Retraining for Balance - Orientation and Balance test (RB-OB)
Retraining for Balance - Audiometric test (RB-A)
Reasons for Training (RFT)
Keystone Visual Skills Test (KVS)
The Kinesthetic-Vestibular Development Model (KVDM)

2.4.4 Procedure

The procedures in this study followed the same pattern as previously described (for details see section 1.2.5) with the obvious exception that the adults came for reassessment either alone or with a relative. Due to work and family commitments resulting in less regular visits the adults needed longer time (M = 37.14 months, SD = 23.24) than the youngsters (M = 29.43 months, SD = 9.71) to complete therapy.

2.4.5 Statistics

A two-way mixed Pillais' MANOVA was conducted with Treatment (before, after) as a within-subjects factor and with Age Group (youngsters, adults) as between-subjects factor for the Physiological test. Two-way mixed ANOVAs were conducted with Treatment (before, after) as a within-subjects factor and with Age Group (youngsters, adults) as between-subjects factor for the following instruments: Orientation and Balance test, Audiometric test and Keystone Visual Skills test (KVS). Although the children and adults showed the same patterns concerning periods of regressions and transformations, the regressions were often stronger among the younger participants. The degree of alignment to KVDM was tested through comparing the two age groups with each other (Mann-Whitney U-test) and with a norm group of 398 treated children (One Sample t-test). The questionnaire Reasons for Training (RT) was evaluated with help of descriptive statistics.

2.4.6 Results

The Results of the study showed significant improvements on all measurements with regard to treatment in line with **Paper I** for both age groups and the main picture indicated small differences between age groups. There were no significant differences between the two age groups or between the age groups and the norm group in regard to KVDM. Although the children and adults showed the same patterns concerning periods of regressions and transformations, the regressions were often stronger among the younger participants. Conclusions were that the same diagnostic instruments and treatment methods can be used for both children and adults with sensorimotor difficulties and that the difficulties can't be out grown.

2.5 **Paper IV.** Catching-up: Children with developmental coordination disorder compared to healthy children before and after sensorimotor therapy

2.5.1 Aim

The aims of the present study were to (a) compare healthy children in terms of sensorimotor maturity to untreated children diagnosed with developmental coordination

disorder (DCD) and (b) compare healthy children to diagnosed children following completed treatment with sensorimotor therapy.

2.5.2 Design

Participants were 298 children, 196 boys and 102 girls, distributed into a Norm group of healthy children (n = 99) and a group of children diagnosed with DCD (n = 199) with a total mean age of 8.77 years (SD = 2.88). Participants in both groups were assessed on instruments aimed to detect sensorimotor deviations (i.e., RB-P, RB-OB and RB-A). The children in the Norm group were assessed at their own schools while those in the DCD group were assessed at the Vestibularis Clinic. During each assessment either a parent or another adult close to the child was present.

2.5.3 Instruments

The instruments listed below were used (for details see section 1.2.4):
Retraining for Balance – Physiological test (RB-P)
Retraining for Balance - Orientation and balance test (RB-O)
Retraining for Balance - Audiometric Test (RB-A)
Teacher Rating Scale (TRS)
Parent Symptom Questionnaire (PSQ)
Reasons for Training (RT)

2.5.4 Procedure

The Norm group

All participants in the norm group were volunteers recruited from different school districts in a middle-sized town in the southeast part of Sweden. After permission from four head masters interested teachers were allowed to sign up for their classes to take part in the study. The teachers called for separate parent meetings where the current author gave an oral presentation of the layout of the study. Thereafter a written summary was provided and parents were free to ask questions. The day after each parent meeting each class received a visit and the pupils were informed in the same way. It was also made clear that a third person related to the pupil should be present at each assessment and that no reward was to be expected. Eventually 103 children signed up and were tested. Four of them were excluded because they had either trained previously or were currently enrolled at the Vestibularis Clinic. Assessments took place in a room, offered by each headmaster, at each school and followed the same procedure as the assessment routines at the Vestibularis Clinic.

The DCD group

All participants in the DCD group were children who had previously completed sensorimotor therapy (SMT) at the Vestibularis Clinic (for details see section 1.2.5). With the composition of the Norm group as a starting point, there were 199 children who had been treated with SMT, in the same age ranges that is, the “5-year-olds” group (58 – 70 months), the “8-year-olds” group (94 – 107 months) the “10-year-olds” group (125 – 133 months), and the “13-year-olds” group (144 – 168 months).

2.5.5 Statistics

Analysis of the study was conducted in three steps (I - III):

(I) Comparisons between children in the Norm group and untreated children from the DCD group with sensorimotor disorder

A three-way Pillais' MANOVA (2 x 2 x 4 factorial design) was applied with Group (norm, DCD), Gender (boys, girls) and Age Category (5, 8, 10, 13) as independent variables. The dependent variables were the subscales of the Physiological test and the total score. Further, a three-way ANOVA (2 x 2 x 4 factorial design) was conducted with Group (norm, DCD), Gender (boys, girls) and Age Category (5, 8, 10, 13) as independent variables. The dependent variable was the Orientation and Balance test. Finally, in order to examine right dominant hearing based on an interval scale, a three-way ANOVA (2 x 2 x 4 factorial design) was conducted with Group (norm, DCD), Gender (boys, girls) and Age Category (5, 8, 10, 13) as independent variables. The dependent variable was the Audiometric Test.

(II) Effects of treatment in regard to the DCD group

Before treatment and after treatment assessments on Teacher Rating Scale (TRS) and Parent Symptom Questionnaire (PSQ) were tested Paired Samples *t*-test. Further, a three-way mixed Pillais' MANOVA were conducted with the children from the DCD group where Treatment (before, after) was the within-subjects factor and Age Category (5, 8, 10, 13), Gender (boys, girls) were the between-subjects factors. Dependent variables were the subscales of the Physiological Test and the total score. Three-way mixed ANOVAs were conducted in regard to RB-OB and to RB-A with Treatment (before, after) as within-subjects factor and Age Category (5, 8, 10, 13), Gender (boys, girls) as the between-subjects factors.

(III) Healthy children in comparison to children treated with sensorimotor therapy

Paired Samples *t*-tests were used in the *before treatment comparison.* However, such a direct comparison was not a reasonable one to make for the *after treatment comparison*, given the effects of maturity shown in **Paper IV**. Therefore tests were performed (Independent Samples *t*-tests) in order to control for natural maturing effects during treatment time (about three years) through a procedure where the after treatment records of the 5-year-olds group (now a group of 8-year-olds) from the DCD group were compared with the 8-year-olds group from the Norm group. Likewise, a comparison was made between the 10-year-olds group from the DCD group after treatment (now a group of 13-year-olds) and the 13-year-olds group from the Norm group. Statistical analysis using Cohen's *d* showed in the untreated comparison a very large effect size ($d = 2.03$) between the Norm group and the DCD group concerning the mean value of the two used motor tests (RB-P and RB-OB), but in the treated comparison the corresponding effect size was negligible ($d = -0.09$).

2.5.6 Results

The results of **Paper IV** showed, in accordance with the first hypothesis of the study that the Norm group performed better on all sensorimotor tests as compared to the untreated children from the DCD group, with the exception of an audiometric test where both groups performed at the same level. Results also showed, after controls for natural maturing effects, that the participants from the DCD group after sensorimotor therapy did catch up with the healthy children, which led to that the second hypothesis was rejected. Concerning additional problems (e. g., concentration problems, mood swings, reading and writing difficulties, and social immaturity) 79 % of the parents perceived at least 'quite some positive change' which were interpreted as a possible sign of stabilization at the level of remission.

2.6 **Paper V.** Developmental coordination disorder: the importance of grounded assessments and interventions

2.6.1 Aim

In 2015, we received a so-called "Tier-climbing Prize" by the journal Frontiers in Psychology for an innovative article (**Paper III**). The award meant that we were invited to submit a 'Focused Review' in order to elaborate the perspective. The review (**Paper V**) had two aims, (a) to follow-up **Paper III** and (b) to fill a gap in literature regarding assessments and interventions of developmental coordination disorder (DCD).

2.6.2 Design

After a short presentation of the status of present research concerning DCD three different approaches to intervention were described. This was followed by a discussion regarding frequently used assessment instruments aimed for children and adults. Thereafter the method Retraining for Balance (RB) was presented and finally the possible advantages of sensorimotor therapy (SMT) for both children and adults were discussed.

2.6.3 Discussion

The central theme of **Paper V** was the importance of grounded assessments and interventions in regard to DCD. So far a grounded approach i.e., an approach, which has its starting point in fundamental neurological development including aberrant primary reflex assessment and inhibition as well as vestibular assessment and stimulation, has, according to the present authors, been missing. This directly connects to the concept of regression. We tentatively proposed that a re-activation and integration of arrested primary reflexes together with vestibular stimulation causes regressions, which in turn are prerequisites for the release and emergence of both physiological and psychological transformations. A speculation was that a possible "unidentified psychological barrier" (Bergman & Norlander, 2005) might be a result of vestibular dysfunction known to affect both emotions and body balance. Our results have indicated that sensorimotor problems in early life do affect not only physiological- but also psychological development and is in line with previously expressed recommendations (Gillberg & Rasmussen, 2003) of physical, neurological and neurodevelopmental examination of all children with learning and behavioural problems. As for now we find it appropriate to include children who show a sedentary behaviour. Our results also indicated (**Paper III**) that sensorimotor problems could be treated within all age groups. It was concluded that the importance of primary reflex suppression and vestibular stimulation as well as a combination of top-down and bottom-up approaches have to be considered in order to develop effective methods for assessment and intervention of DCD.

3. GENERAL DISCUSSION

3.1 Is there a need for a grounded approach to DCD?

3.1.1 A start from the beginning would not be wrong

When a house is built the work is done in a certain order, which means starting from the bottom and moving up. A stable foundation is necessary in order to secure the walls and to hold the roof. Once the foundation is laid and the walls are raised, girders are laid to hold the second floor. A similar order has also to be used when a house is in need of a full restoration. These images have considerable similarities with how the method Retraining for Balance was used in our studies (**Paper I, III, IV**) and also with how parts of the diagnosis criteria for DCD was formulated. The DSM-5 (American Psychiatric Association, 1994, 2013) stated that symptoms such as a delayed achievement of motor milestones must have been visible during the early developmental period and could not to be explained by medical or intellectual reasons. Further that some children with DCD might show Neurological Soft Signs or neurodevelopmental immaturities. Causes for a delayed sensorimotor development should therefore, obviously, be searched for at the beginning of the developmental chain and then accordingly approached through a hierarchical and maturational perspective.

3.1.2 A grounded approach to sensorimotor development

The method Retraining for Balance is to be regarded basically as a process-oriented method emphasizing the importance to identify underlying sensory and motor difficulties, which prevent the individual from developing his or her sensorimotor proficiency. Following our results in **Paper I-IV**, the concept 'grounded' was introduced in **Paper V** in order to strengthen the significance of assessments and interventions strongly connected to fundamental neurological development. While resting on a solid foundation, the method has so far indicated its suitability for assessments and interventions in all age groups when it comes to DCD but, as proposed in **Paper V,** it will also be useful when it comes to diagnosing persons showing a sedentary behaviour. A grounded approach like Retraining for Balance has been missing within the field of DCD research. Therefore our results could be viewed as an answer to a call from Wann (2007) who wrote that, in children who exhibit specific coordination deficits "there must be common perceptuomotor subsystems that are poorly developed or refined" (p. 405) and continued that it would be a challenging task to identify them. The results in **Paper I-IV** have shown that examples of such neurological subsystems are likely to be the vestibular system with its connections to primary reflexes.

3.1.3 A sedentary behaviour and DCD could both be parts of a continuum

A global problem today is the fact that many children and adolescents, from early age, are physically inactive and occupied with passive assignments instead of being active with play and other daily movement activities (Aubert et al., 2018). Recently physical inactivity and a sedentary behaviour, due to increased screen time, were added to the 'Environmental stress hypothesis' (Cairney, Veldhuizen & Szatmari, 2010; Cairney, Rigoli & Piek, 2013), which aims at investigating stressors connected to DCD (Caçola & Lage, 2019). An association between an increased screen time and anxiety and depression was lately reported by Khouja and colleges (2019). The tendency toward a spreading of a sedentary behaviour is one reason why an interest for more movement education in schools has increased lately.

Another reason is a possible link between movement and an improved academic performance (Mualem et al., 2018). Therefore it is not strange that the concept of 'Physical literacy' has received increased attention lately (see section 1.2.1). In order to create a lifelong interest for movement the concept stresses motivation, confidence and the importance of development of movement patterns as well as the ability to understand the health benefits of movement and an active life. The question remains though, whether or not the concept will be of use for those children who from the very beginning lack both confidence and motivation. These children might very well understand the health benefits but they just can't take part as expected.

Could there possibly be other factors besides an increased screen time, which contributes to why some children are more at risk for developing either DCD or a sedentary behaviour or both? (**Paper V**). Or is it in fact the children who from the beginning lack fundamental prerequisites for the development of sensorimotor skills who are affected? If so, would it be appropriate to give them a start anew using a 'grounded' approach to sensorimotor development? From the results in our studies (**Paper I-IV**) the answer is yes.

3.1.4 Is it possible to remove the ever present gravity from the conceptual framework?

We have published our results at a time when a Dynamic Systems Perspective (DSP) has been the most popular approach to motor development and when neuro-maturational theories have lost their diagnostic value. However, from our point of view, it does not have to be a question of either or. As stated in **Paper V** and further explained below, the method RB is a blend of different approaches, not least a Dynamic Systems Perspective. Referring to an ecological approach and to a DSP, Bonney and Smits-Engelsman (2019) suggested that future tools to assess child development should build on contemporary theories of motor development and considered the interaction between the environment and the child to be of special importance. The complexity of environmental factors and their interactions in relation to adolescents, adults and DCD have been thoroughly accounted for by Tal Saban and Kirby (2018a, 2018b). Such interactions may be regarded as a *horizontal* connection where the person socializes, learns and acts in the world. However interactions between the person and gravity may also be considered, that is a *vertical* connection. Going back several years, the late Esther Thelen, a pioneer within the field of dynamic systems and child development, described in a co-authored article (Kamm et al., 1990) how the child, in a constant field of gravity, experiences and produces its own movements. It seems though as the role of gravity within the DSP has faded over the years as Goldfield and Wolff (2004) explained that different parts of a system are able to self-organize without any external agent. According to our observations it is the other way around. Gravity is an ever-present agent all through the life span (*e.g.* Jamon, 2014; Nicolis, 1993). Especially during the first years of life gravity is a tough opponent to conquer and for reasons hitherto unknown some children, seemingly otherwise healthy, are the losers of that battle. The consequence is likely to be an arrested development, which untreated would primarily affect the development of sensorimotor skills but also have secondary effects on the ability to concentrate, as shown in **Paper I** and **III,** and to build social bounds as was argued by Ayres and Robbins (2005). In order to release the development the treatment has to start with the removing of the hindrances.

3.1.5 Removing the hindrances is a process

It was suggested by Goldfield and Wolff (2004) that any general theory of motor development should address questions like, 1) if and how can primary reflexes prepare for the development of more complex motor skills and 2) where do the reflexes go when they

disappear and 3) what is meant by emergence? In order to answer these questions both the aspect of primary reflexes and the aspect of gravity and the vestibular system have to be considered.

From early foetal life primary reflexes like the Moro reflex and the vestibular system are closely interwoven (**Paper V)**. Although it's not yet clear how active the vestibular system is in utero (Piontelli, 2015) it has been suggested (Casaer, 1993; Prechtl, 1993) that an increase in oxygen tension at delivery will switch it on. Together with other reflexes, the Moro is checked for at a first neurological examination and then expected to be suppressed during the first 6 months of life. However, retention of the ontogenetically old Moro reflex constitutes a hindrance for ontogenetically younger primary reflexes to fulfil their work as retention, practically, will keep them contained and an arrested development is likely to follow. Retention of the Moro reflex is associated with an increased sensitivity to vestibular stimulation, which in turn will be a hindrance for physical experiences and thereby for further sensorimotor development. It is important though to keep in mind that retention of a reflex is not a matter of either or.

The scoring used at the neurological examination of a new-born follows a continuum (*e.g*. Prechtl, 1977) and so was the scoring at the RB-P assessments in **Paper I, III, IV**. This could imply that even a low scoring on a test could be a subtle hindrance for development. Therefore should any deviation from what is expected to be normal be followed-up in order for normal development to take part. As stated in **Paper V** the method Retraining for Balance partly holds a Dynamic Systems Perspective. Key concepts within DSP are the aspects of self-organization and emergence both of which are fundamental also for RB. In our conceptual model for how the training works it is due to the external agent gravity and its influence on the vestibular system that the reflexes are suppressed and the development is released. When we used foetal and neonatal movements in combination with vestibular stimulation in order to suppress primary reflexes (**Paper I, III, IV**), we experienced the emergence of postural reactions and gross motor milestones i.e., without training of the movements as such. This frequently happens to clients who skipped milestones such as 'tummy-crawling' and/or 'creeping on hands and knees' during infancy and still showed no signs of these competences when assessed at Vestibularis. This ought to be an indication for a re-evaluation of the traditional neuro-maturational perspective (Kamm et al., 1990).

3.1.6 Is motivation a driving force in sensorimotor development?

As mentioned in **Paper V** the DSP holds that motivation is a driving force in motor development. It might as well be true for some but those concerned in this Thesis have often had a good motivation but have failed anyhow. From our point of view due to an arrested development, this will keep the person more or less contained. A retained Moro reflex is often to be detected, within all age groups, at the first assessment at Vestibularis. By experience through conversation with clients and parents/spouses we have learned that a retained Moro reflex not only affects motivation but also is connected to a lack of confidence. This becomes obvious when the reflex is suppressed and a better confidence slowly emerges and the motivation to movement increases. A retained Moro reflex has also shown to be connected to baseless fear. The connection to fear itself is not strange since the Moro reflex is a 'lifeline', a part of our inbuilt survival kit. As mentioned above the reflexes are to be supressed, but they are also expected to reappear in urgent situations or when an elite athlete is about to carry out an action demanding high skills. For example a basketball player who uses the asymmetrical

tonic neck reflex when scoring and a springboard diver, flexing the body using the symmetrical tonic neck reflex (Goddard Blythe, 2009).

However, if the Moro reflex is more or less constantly present it might create false fears, which will induce stress and an increased level of cortisol will follow (Grillon et al., 2006). It was suggested by Sharot (2011), that if the brain stays occupied with fear it would be more difficult to grasp new information. An adding of Sharot's suggestion to our conclusion in **Paper III** will give even stronger reasons for why early sensorimotor difficulties have to be taken seriously. Returning to the concept of Physical literacy as described above, our results show that in order to make a difference with all children one has to reconsider those who early in the project show a lack of motivation, courage and motor proficiency in general. For them the training of motor skills is too advanced. The solution to their problem has to be found in a grounded approach to intervention.

3.1.7 It is not all about maturation

According to the DSM-5 (American Psychiatric Association, 2013) it is not recommended to diagnose DCD before the age of 5 years. The reason given is that there are still possibilities for further maturation. This is true but if the child is late and the disorder is suspected it should be expected that maturation is not enough. Through the results in **Paper I, III, IV** we have confirmed previous studies, which have shown that one doesn't grow out of sensorimotor difficulties. Although all age groups in our studies have benefitted from training, **Paper I** showed proficiency effects of biological development since the older group performed better than the middle and the younger group on RB-P and RB-O. Results in **Paper III** showed no significant difference in terms of sensorimotor abilities between a group of youngsters 11 years and older and a group of adults 18 years and older which from our point of view underlines the importance of an early detection of motor difficulties. An early detection is important because sensorimotor behaviour will become more adult like around puberty, which not necessarily mean that difficulties seen before have vanished. Results in **Paper IV** showed that children from the DCD group aged 8-13 years, after treatment performed significantly better on the RB-P compared to children of the same age from the Norm group. This could possibly be interpreted as a notion that some children from the Norm group had a non-diagnosed DCD.

3.1.8 A 'Vision skills test' for ocular accommodation

Although a connection between DCD and an insufficient ocular accommodation has been known for a long time it was mentioned only recently by Blank and colleges (2019). For many years the connection has been observed and assessed at the Vestibularis Clinic the use of the Keystone visual test (KVS) before and after training. The rational has been the relation between ocular function and the vestibular system through proprioception (*e.g.* Cogan, 1972; Jamon, 2014). In our first study (**Paper I)** the test was used for concurrent validation of other sensorimotor tests and results indicated that visual skills and motor capacities correlated with each other. A similar correlation was confirmed in a recent study (Andrich et al., 2018), which showed a relationship between some retained primary reflexes and visual skills deficit in children. In **Paper III** the KVS was used in order to examine improvements on visual skills, that is ocular accommodation, and results showed that both the younger group and the group of adults had perceived significant improvements during the time of training. However, at the first assessment results showed that both groups performed at the same level but after training the youngsters performed significantly better than the adults. The difference after

training could possibly be explained by the fact that some of the adults had reached the age (M = 35.21, SD = 10.73) when presbyopia, the age-related gradual loss of accommodation, had begun to set in. If so, it is even more interesting to notice that the adult group improved significantly during training. This is against present knowledge, which holds that once the decline has started it will continue (Charman, 2008).

As explained in **Paper I**, vestibular stimulation has been used during training, primarily in order to facilitate the integration of the primary reflexes but also, since 1999, as a way to increase the ability for ocular accommodation in terms of higher scoring at the KVS-test. We were put on track through a girl who was 10 years old and who had previously completed her training according to RB with good results besides when it came to the rotation on the swivel chair, which she never had fully accepted. At the time for her start and completion of the training Vestibularis didn't own a Keystone Ophthalmic Telebinocular (KOT). We had, however, a habit of doing a re-cheque of our clients after 6 months and another after 1 year just to secure that the primary reflexes stayed suppressed, which they almost always were. When the girl returned for her first re-cheque the primary reflex scoring was unchanged and so was her resistance to the rotation. According to her parents much in the girls life had changed to the better but there were still academic difficulties and slight concentration problems. By now Vestibularis had bought a KOT, she was tested and the results revealed a remarkable underscoring, 18/66 points. The girl agreed to give the rotation in the swivel chair a second chance and at the re-assessment 7 months later she scored 62/66 points. We were also told that her performance at school had improved. This experience became a 'watershed' for the work at Vestibularis.

So far we had connected and defended the use of vestibular stimulation mainly in accordance with Ornitz (1983) and with Guyton (1991) as described in **Paper** I, but it appeared to us that we might have missed something vital until then. The result of the KVS-test did not only tell the status of the ocular accommodation it also seemed to reveal how well the vestibular stimulation had been appreciated during training. The KVS-test results among adults in **Paper III** is difficult to explain through existing literature but is likely to point in the direction of vestibular stimulation. This direction might be supported by Clark and colleges (1975) who studied the vestibular-ocular accommodation reflex in 10 young men after 30 seconds of angular rotation and hypothesized that the increase in accommodation ability, which they found was due to the reflex. The notion by Blank and colleges (2019) to suggest common pathways between DCD and insufficient ocular accommodation is not only a deviation from DSM-5 (American Psychiatric Association, 2013), which states that a diagnosis is set, "if the coordination difficulties are not better explained by visual impairment or attribute to a neurological condition" (p.75). It also brings another valuable clue to follow, for an early detection of DCD.

The original KOT has been around for several decades and was used as a screening instrument for visual skills in Swedish schools during the 1980s but was later put aside although its usefulness had been documented in earlier studies (*e.g.* Coren & Porac, 1975; Sloane & Rosenthal, 1960). In connection to the results in **Paper I, III** and to the suggestions from Blank and colleges (2019) it might be reasonable to give the KOT a second chance.

3.1.9 A 'Vision skills' test for horizontal tracking

Another aspect of 'visual skills' is the ability for horizontal tracking, i.e., smooth pursuit eye-movements, a competence with essential importance for both reading and writing

capabilities. In typical healthy children this ability is matured by the age 7 years but it is to be expected that when motor performance is impaired, as in DCD, there will also be a reduced oculomotor capability (Ingster-Moati et al., 2009; Robert et al., 2014). This was confirmed in the results of the subtest 'Eye movements' in **Paper IV** where the differences before training between the Norm group and the DCD group, in all age groups, were very wide. However, after the training all age categories in the DCD group showed better results than the Norm group. These results are important by at least a couple of reasons. First, it indicates that a risk for future reading disabilities could be identified earlier than previously proposed. In Sweden the average age for diagnosing reading difficulties, such as dyslexia, is 13 years (*e.g.* Nilsson Benfatto, et al., 2016). Second, motor difficulties should be regarded when screening possible academic problems (*e.g.* Gillberg & Rasmussen, 2003).

3.1.10 Attentional problems in both DCD and ADHD

Comorbidity between DCD and other neuropsychiatric disorders is well known and the overlapping with ADHD is suggested to be most frequent and the rate is proposed to be 50% or higher (*e.g.* American Psychiatric Association, 2013; Blank et al., 2019). Presently ADHD is a rather well defined disorder (Edebol et al., 2012; Hoogman et al., 2017) and a couple of variations have been observed. As mentioned in **Paper V** this is not the case with DCD although the importance of an early detection of the co-occurrence between ADHD/DCD became obvious a long time ago, in a longitudinal, community based follow up-study, at age 22 years, by Rasmussen and Gillberg (2000). The authors found that individuals diagnosed as having both DCD and ADHD had faced more setbacks than those diagnosed with only ADHD. In the ADHD/DCD group criminal offending, alcohol abuse and reading problems were over-represented. This group also showed a lower educational level. Later, Kirby and colleges (2007) revealed a lack of knowledge concerning DCD among both psychiatrists and paediatricians and Gillberg and Kadesjö (2009) wrote that DCD, traditionally, is considered to belong within the territory of a child neurology or developmental pediatrics while ADHD, typically falls within the domain of child psychiatry and psychology. This split between different fields of expertise might be one explanation as to why DCD still is regarded as a 'hidden problem' (see 1.1.1). Still another explanation could be, as mentioned in **Paper V**, that a consensus when it comes to assessments and interventions of DCD is still missing. DCD and ADHD in combination ought to be expected to increase an individual's tiredness not the least due to the brain's need to compensate for poor balance and a lack of motor automation (see 3.2.1). In order for the individual to 'stay awake' the brain tries to compensate with an overactive behaviour. This might be a probable explanation as to why ADHD medications containing stimulating substances such as methylphenidate or amphetamines are of help not only when it comes to reducing hyperactivity but also in regards to an increased ability to be attentive and to concentrate.

Our empirical results (**Paper I, Paper III** and **Paper IV)** showed significant improvements after sensorimotor therapy regarding 'Inattention' as measured by the Teacher Rating Scale and the Parent Symptom Questionnaire (see section 1.2.4). After training results from both tests indicated significant improvements on all subscales including 'Inattention' and the conclusion was that problems of attention and concentration should be viewed as connected to sensorimotor difficulties. From these results we have reasons to suggest that the improvements on all subtests are due to the supressing of primary reflexes in combination with vestibular stimulation. It is also possible that an improved vestibular function contributes to an increased arousal, which could imply that sensorimotor training might have similar effects as medication for some children. This is worth to consider since some children could

be either sensitive to prescribed ADHD medication or not responding to it (Esparham et al., 2014). However, at the Vestibularis Clinic we have positive experiences from a combination of training and medication. Occasionally, children who were on medication have started the training. There are also children who have started medication during training.

3.1.11 Are there unidentified perceptual and motor problems in young girls?

In general DCD is described as a boys' disorder, estimated to affect more than twice as many boys than girls (Cairney, 2015). This holds true also at the Vestibularis Clinic where the ratio over the last 20 years have been about 20% girls and 80% boys. These figures were reflected in **Paper I**, in which 181 boys and 51 girls participated. The question is though if these figures mirror reality? As argued in **Paper IV** there are different theories about gender discrepancies and it has already been mentioned in this Thesis that DCD is regarded as a 'hidden problem'. In **Paper III** one man and thirteen women participated, all of whom had on their own initiative contacted the Vestibularis Clinic and stated a wish to be assessed for sensorimotor problems. An open question which was raised in **Paper III** was why it has been mostly women who voluntary sought therapy? This question could presently be answered with yet another question. Are there subtle perceptual and motor problems among young girls still to be identified? Future studies might own that answer. Until then we can note that there were only few gender differences (**Paper I, Paper III** and **Paper IV)**. In these studies girls performed better, prior and after therapy, on 'eye movements' 'balance' and 'proprioception'. The differences might be due to an earlier maturation of girls' vestibular system (Quatman-Yates et al., 2012) but the question has to be left for future studies to investigate.

3.1.12 Yes, there is a need for a grounded approach to DCD

In **Paper IV** it was shown for the first time that a group of children with DCD was able to catch-up with healthy children through sensorimotor therapy (SMT) using the method Retraining for Balance. In **Paper I** and **Paper III** it had already been shown, also for the first time, that the same assessment and intervention could be used with all age groups i.e., from young children to adults. In order for us to build a conceptual model for a more thorough understanding of the method the starting point was the view of RB as a process oriented, hierarchical and basically bottom-up approach but as suggested in **Paper III** and explained in **Paper V** where we added two concepts from the Dynamic Systems Perspective (DSP), self-organization and emergence. In **Paper I** and **Paper III** the gross motor milestones, 'rolling', 'tummy-crawling' and 'creeping on hands and knees' were defined as emergent properties due to primary reflex inhibition and vestibular stimulation. This view stands in contrast to the DSP by three reasons: (a) for RB gravity with its influence on the vestibular system is a fundamental external agent, and the concept 'perceptual priming' was introduced in **Paper V**; (b) For RB it is the integration of primary reflexes together with vestibular stimulation that brings motor development forward; (c) Within RB the development and emergence of gross motor milestones (GMM) are of great importance. In connection to 'emergence' the concept 'bifurcation points', borrowed from physics and chemistry, is suitable as a possible explanation to when and where the GMM appear (Briggs & Peat, 1990; Prigogine & Stengers, 1984; Prigogine, 2003).

A bifurcation point is a place of branching where the (nervous) system is, through its self-organization, about to undergo a transformation and given a choice to take a new direction. Which direction the system takes depends on the strength of the force that drives the transformation. In **Paper V** this was described as vestibular stimulation (perceptual

priming) igniting and nourishing the nervous system, supporting the suppressing of reflexes and thereby develop a certain milestone. The rational of RB is to imitate natural development in order to 'bring out' and 'transform' what is already there and the bifurcation points are in this way regarded to be milestones in the evolutionary history of the system (Briggs & Peat, 1990). In **Paper I**, results showed not only significant improvement on gross motor milestones after training for both genders but also that boys performed significantly better than girls. This difference between boys and girls is contrary to what could be expected but an explanation has to wait until further studies. A reasonable explanation though for the improvements during training for both genders could be that the participants during their first year of life failed to develop their 'true' GMM. It is highly possible that the branching, due to a too weak force, had reached a lower level of motor behaviour (a lower bifurcation point) than expected but through appropriate training expected levels could be attained (*e.g.* Laszlo, 1993).

Unfortunately most parents lack both the knowledge about what to expect from their child during the first year and what they could do to enhance development. This is one reason why it is of importance to reach a consensus within child medicine and child psychiatry on how to view early sensorimotor development. A grounded approach to DCD is needed but the framework has to be extended not the least in order to get a better understanding of the psychological part of SMT (**Paper II)**. The first step toward an extension was taken in **Paper V**.

3.2 Toward an extended framework of a grounded approach to DCD

3.2.1 From where should we start? From the brain, the body, the environment…or?

Brains in general are built after the same principle, using similar but not identical architecture. It is not only the given biological conditions that shape the development of the brain, since the environment already in utero affects what the brain content becomes (Jamon, 2014; Ronca & Alberts, 2000). This means that although we all look similar we are neurologically different from one another (*e.g.* Feldman Barrett, 2009). In order to expand the theoretical and practical framework of RB and thereby increase the understanding of how physiological behaviour (*i.e.,* sensorimotor) and psychological behaviour interact, it is helpful to consider the brain as embedded in the world through the body (Bergström, 1989; Clark, 1997; Dotov, 2014; Feldman Barrett, 2014; Llinás, 2002). The concept of Brain-Body-World Interaction (BBWI) (Clark, 1997, 1999, 2016) incorporates earlier developed tools and methods such as those available through the Dynamic Systems Theory (Prigogine & Stengers, 1984) as well as recent holistic research on brain function (*e.g.* Bertolero & Bassett, 2019; Enander et al., 2019). The holistic approach is shared by Feldman Barrett's 'Conceptual Act Theory' (CAT), which holds an evolutionary view and hypothesises that emotional episodes are emergent states with functional traits that are different from physical states (Feldman Barrett, 2014). According to CAT the main task for the brain is to calculate and regulate the body's energy balance. There is a continuous communication between the brain and the body, a sort of perpetual reconciliation, where the brain checks how it can create or re-create balance between intake of and expenditure of different kind of energy. This process is necessary both for our environmental adaption and for how we feel. With the theory comes also that we construct our emotions from predictions, true or false and from uncertainty. In this way, for example, the amygdala may not encode fear but rather uncertainty (Feldman Barrett et al., 2016; Nierenberg, 2019).

3.2.2 The starting point for an extended framework would be a brain-body-world interaction (BBWI) perspective

The aim of **Paper II** was to get a better understanding of the physiological and psychological regressions and transformations, which were experienced during the training process and the analysis disclosed three periods of regression and four periods of transformation. The regressions described in **Paper II** are not to be confused with the phenomena, which traditionally in literature are labelled neurodevelopmental regressions or just developmental regressions. (Neuro) developmental regressions during infancy and early childhood have a hitherto unknown etiology but are often connected to autism spectrum disorder (Parr, 2017; Scott et al., 2017). Since occasional drops in performance are rather common also among healthy children (Rochat, 2001) it is of importance to be observant (Sreekantam & Wassmer, 2013). Neither should the regressions reported in **Paper II** be confused with regression among hospitalized persons (*e.g.* Lokko & Stern, 2015). The phenomena experienced during the process of RB were more like those that are usual during normal early child development and they were typically followed by transformations. This notion is in agreement with Kestenberg (1979), who wrote that the aspects of regressions and progressions are natural characteristics in young people's development, and with Loewald (1978, 1981) who argued that both aspects are complementary and necessary phases for psychic organization.

Winnicott (1954/2007) considered therapeutic regressions to be part of a healing process in healthy persons. He held the view that any healthy individual, during early development, could face some kind of failure in environmental adaption and to which a defence became necessary. A natural reaction to the failure could be to freeze the situation. Later, if and when the environment makes adequate adaption, the failure situation could be re-experienced and unfrozen. In this way the regression could be, as described by Balint (1968), a way to a new beginning or by Battegay (1970), a latent hope for the future. In the framework of RB the concept 'regression in the service of the ego' (Kris, 1954) is the most suitable denomination (here-after regression) because of the term's incompatibility to analytic treatment. Instead it can explain and describe reactions in a process of artistic creation (Balint, 1968; Guttman, 1960). In order to cope with the regression Kroebner (1963) wrote that the individual uses his or her preconscious function in order to be playful and utilize ideas and feelings belonging among past experiences. In this way the contact with primary mental and physical positions are maintained (Yaniv, 2018) and regression can thus be viewed as both an act of creativity and an act of personal growth (Knafo, 2002).

Regarding the three periods of regressions, each one emerged in connection to a certain (physical) exercise. This is in line with Dynamic Systems Theory (*e.g.* Prigogine & Stengers, 1984), which tells that a system is unstable at transition points. It is likely that this aspect is transferable to the brain and the nervous system because the same mechanism, which pushes developmental change forward also unmask the immature brain to disadvantageous events. Therefore it becomes more difficult for an immature brain to keep equilibrium between homeostasis and plasticity. Homeostasis, at the network level, changes synaptic connectivity and stabilizes learning (Dennis et al., 2013) while, as a response to environmental impact, neural plasticity assists the nervous system in the reorganization of neural networks (Johnston, 2009).

Of interest to notice is also that the first transformation emerged in connection to RB:s very first exercise. This exercise is a slow rocking movement, an imitation of the fetus' first movement (Morris, 1991). Going back to the 11:th week after conception, the exercise is

carried out in close connection between the child and the mother. Although a consensus is lacking (see section 1.1.9) the rational in RB is that this movement is vestibular in origin and that it was first experienced in the womb i.e., in absolute proximity between mother and child (Zohar, 1991). This first transformation was, and still is, often experienced as if the child becomes more 'easy going'. By using a BBWI-perspective together with a core suggestion from the CAT i.e., the importance of allostasis and interoception (Feldman Barrett, 2017), it is possible to suggest an interpretation of why the transformations described in **Paper II** can be accomplished.

3.2.3 Two ways to connect to the world

Hitherto RB has stressed the importance of gravity and its influence on the vestibular system. As mentioned above, I would like to conceptualize this connection to the world as a vertical connection. Such a connection has, to my knowledge, only once (Chiel & Beer, 1997) been explicitly mentioned in literature concerning the BBWI-perspective. Most probably because gravity is taken for granted but as our results in **Paper I, III** and **IV** have shown, this is most probably a mistake. Frequently mentioned, though, is the horizontal connection to the world. This connection implies our being in the world with all its possible interactions. However, for a BBWI-perspective to make sense both connections must be accounted for. Could it be a vertical connection that Clark (2016) implicitly had in mind when he stressed the need for sharper model for the integration of cognition, action and perception? Put in the context of the transformation mentioned above, the child, with body and brain, is embedded in the world (environment) horizontally by the mother and vertically by gravity. According to the Conceptual Act Theory (CAT) the brain evaluates and calculates the inflow of energy in order to create homeostasis and to regulate interoception. My tentative suggestion as to why the transformations were accomplished is that the movements of slow rocking generated proprioceptive, tactile and 'new' vestibular sensations to the brain, which in turn generated processes toward homeostasis. I use the concept 'new' because part of the rationale behind RB, is that the child's nervous system, by reasons unknown, so far has been unable to fully appreciate vestibular impact.

3.2.4 Bounding, caregiving and gravitational security

The concept 'new' vestibular sensations gets its meaning from that part of the RB rational which tentatively suggests that some children might fail, by reasons unknown, to get a proper 'grip of gravity' at delivery i.e., the vestibular system is not fully activated (Casaer, 1993; Prechtl, 1993). As explained in **Paper I, III, IV** and **V** this lack in vestibular function is hypothesized to be one reason why the primary reflexes remain more or less unsuppressed. Beside a deviation from normal motor development (Holt, 1991) a not fully activated vestibular function at birth is likely to bring a 'gravitational insecurity' (see section 1.1.9) resulting in subtle signs of inconvenience and spatiotemporal distress (Gilfoyle et al., 1990) and misconceptions in the bounding relation might arise. The child is not able to fully appreciate the mother's care due to insecurity and the mother could get the impression that she is not a good mother (Kandel, 2005). This is an example of how primary perceptual priming might fail (**Paper V**) and also an example compatible to the CAT, which hypothesize that the amygdala does not encode fear but uncertainty (Feldman Barrett et al., 2016). My conclusion is that there are strong reasons to connect signs of a delayed sensorimotor development with probable bounding difficulties primarily with mothers. However, during the first exercise according to RB the child receives a second chance to adapt to gravity, and mother and child are given a new possibility for rebounding.

The development of 'gravitational security' is important also for healthy children and should not be taken for given. As described in **Paper I** the first year of life is a constant struggle to defy gravity. There are always hindrance to conquer and goals to reach. In this way gravity creates a spatiotemporal stress, which is good for the child (Gilfoyle et al., 1990). To get knowledge about its own body in space i.e., the world, the child has to interact primarily with parents and siblings. Unfortunately neither policymakers nor parents (how could they?) fully understand the importance of assistance with this 'hard' sensorimotor work during the first years of life. Schilder (1964) suggested that not only should parents be taught how to carry and handle their child, they should also be aware of their own emotional balance. The last part of the sentence put quite a demand on parents but I agree on his suggestion to educate parents. A prerequisite for a successful BBWI - perspective is the embedding of the brain-body system in both vertical and horizontal connections.

3.2.5 How should regressions be interpreted?

As described in **Paper II** the first transformation turned into the first period of regression after a couple of weeks. The first and the second periods of regressions were in a way similar to each other. Both were characterized by an increased childishness and a stronger wish to connect to mother. This wish increased during the second regression. The second regression was also characterised by a tendency for unmotivated sadness and tears, an increased interest in their own toddler-time and an increased wish socialize with family. During the last period of regression the temper became more firm and the child more defiant. Each period of regression started around the time for the introduction of a new, certain exercise. This notion of integration points in the direction hypothesized by the CAT (Feldman Barrett, 2014) which says, "*the workings of each system must be holistically understood within momentary state of the brain, the body, and the surrounding context*" (p. 292) and shares similarities with one conclusion made in **Paper II**, that is, the regressions may be part of the 'multitude' (manifold) of possible but not yet fully realized sensorimotor (physical) and psychological behaviours. If so, there are strong reasons, not the least from a psychological point of view, to recognize the value of monitoring a child's sensorimotor development and if necessary, start an intervention as early as possible. From this perspective the present recommendations (American Psychiatric Association, 2013; Blank et al., 2019) might be reconsidered. As for now the recommendation for a DCD diagnosis is from five years of age. The recommendation is due to the spontaneous catching-up with some children and reported difficulties to, in a reliable way, assess very young children. An interpretation of the meaning of the regressions would risk bringing about speculations. Therefore I find it better to stay with observed reality i.e., the regressive behaviour, which emerges during training is similar to behaviour seen in very young children. My conclusion from this observation is, as mentioned in **Paper V,** that also the psychological development had been arrested but the training brought release. The similarity to Winnicott's theory (see section 3.3.2) and his use of the concepts 'frozen' and 'unfrozen' is obvious. Tentatively and in agreement with one line followed in this Thesis, I suggest that there are more to be said about the value and importance of both proper vertical and horizontal connections during infant development. In times of increased sedentary behaviour and mental illness among young people the results from mainly **Paper IV** give us reason to believe that a grounded approach including a Brain-Body-World Interaction (BBWI) perspective to DCD should be an option in order for us to create a healthier society. It is time to stop regarding DCD as a 'hidden problem'.

3.3 Future directions

3.3.1 Remission

The concept remission can be described as the individual developing a good enough function in order to function well in society with the help of various strategies (Norlander et al., 2015). Stabilization at the level of remission with improved quality of life as a consequence could also constitute a better starting point for an even greater recovery (Weiden et al., 1996). Although **Paper I**, **Paper III** and **Paper IV** indicated improvements for a majority of the participants we do not know which level of remission they have reached. So far the concept has been put forward within fields such as schizophrenia research (*e.g*. Helldin et al., 2006, 2007; 2009) but besides our mention in **Paper IV** it is so far missing within DCD research. In **Paper IV** we rhetorically asked whether the concept of remission would be of importance for future DCD research. As for now and from a BBWI-perspective the answer is more yes than no. During training the nervous system has reached new bifurcation points (see section 3.2.13) and in accordance with General Systems Theory (von Bertalanffy, 1993) these new levels are 'steady states' i.e., they are steady and in accordance with Dynamic Systems Theory irreversible (*e.g.* Prigogine & Stengers, 1984). Put in context of RB, the 'restoration image' (see section 3.2.1) could stand as a description of the process and the reached milestones could be considered as 'girders' within the nervous system. In our conceptual model this means that the individual has gained improved physical brain-body stability. In **Paper II** this was described as a transformation where participants were more interested in physical activities. From the 'world' or environmental perspective this could imply that once the vertical connection is better established it would generate prerequisites for enhanced horizontal connections (*e.g.* Vanderplasschen et al., 2013). In order to keep the level of remission or even better to improve it, parents, teachers, friends and society in general have to encourage further development. This integration is suggested to start during intervention as soon as the individual shows interest.

3.3.2 Equifinality

From a systems perspective the concept equifinality have two meanings within developmental psychology, (a) the same end point can be reached by developing organisms, which have different initial or early conditions, and (b) although using different pathways or routes organisms sharing equal initial conditions can reach the same endpoint (Gottlieb et al., 2006). It implies also a possible explanation as to why development might be quicker or slower depending on person and which route that was chosen (Butterworth & Harris, 1998). The concept was introduced in **Paper IV** with a purpose to emphasize the importance to compare not only different approaches of sensorimotor training but also to compare the effect of sensorimotor training to other efforts such as behaviour modification and medication.

3.3.3 Vestibular function

There is a growing interest in vestibular development and the number of publications covering vestibular cognition from different research angels seems to have increased (Besnard et al., 2015; Cohen & Lewis, 2018). One angel of special interest, which is just about to be investigated, is the hypothesis of a possible link between dyscalculia and vestibular function (Smith, 2012). A recent small sample study by Moser and colleges (2017) showed worse math performance in a group of patients with vestibular neuritis compared to a group of healthy people. The difference between the groups could not be explained by either education or

processing speed. In **Paper II** analysis showed that academic proficiency improved during training although for some, difficulties with mathematics remained. How come that reading abilities in general improve but mathematics stay difficult? One daring and speculative suggestion is that we have a very basic mathematical capacity connected to the gross motor milestones and then also to our vestibular function. According to Piaget and his theory of the sensorimotor stage, an infant understands the world through his/her sensory and motor experiences. According to the conceptual model of RB a prerequisite for this ability should be that the vertical connection is in order. The concept 'geometry' means measurement of earth or land. During the first year of life the infant has the opportunity to view the environment from different position and also, through its own body, 'measure' the room by rolling, 'tummy-crawling', 'creeping on hands and knees' and finally walk in erect position. I suggest that these spatiotemporal experiences might contribute to a basic sense of time, space and 'rudimentary mathematics'. Results from a recent small sample study, aiming to investigate the efficiency of an integrated physical activity (PA) and mathematical (geometry) program among four graders, showed that the integration between mathematics and PA was more effective than traditional math teaching (Hraste et al., 2018). Another study (Frick & Möhring, 2016) suggested a relation between spatial- and balance skills among children aged 6 years. From this it might be concluded that there could be a connection between physical activity and the ability to learn geometry as well as between balance ability and room perception but further studies is suggested to examine why. Given the connection between hippocampus and the vestibular system (Jamon, 2014) and research from the Nobel laureates Moser and Moser (2016), which showed that humans as well as other mammals build internal environmental maps it would be interesting to know which role the vestibular system play.

3.4 Limitations

One limitation of the present Thesis is that the same two therapists performed all interventions, which makes it difficult to ensure whether or not the personalities of the therapists might have had influence on the results. A private clinic such as Vestibularis might invite to personal relations in a way, which is difficult to achieve in common settings. However, a previous study (McPhillips et al., 2000) using a similar approach to sensorimotor training as RB did also show good results. Another limitation is that a randomised controlled study is missing so far. On the other hand Paper IV, which was a study comparing a Norm group of healthy children with a group of children diagnosed DCD, gave good indications for the training effect.

3.5. Some reflections on my contributions and experiences

3.5.1 Contribution to knowledge

In my opinion, I have contributed to the research as follows: (a) Developed and psychometrically tested new measuring instruments in order to describe sensorimotor status before and after treatment. (b) Have shown that the method Retraining for Balance produces good results in the treatment of DCD. (c) Have for the first time analysed a scenario in which re-activation and integration of arrested primary reflexes together with vestibular stimulation caused regressions, which was shown to be prerequisites for the emergence and release of both physiological and psychological transformations. (d) Have shown that even adults with

DCD can be treated using the same methods that work for children. (e) Have shown for the first time that children diagnosed as DCD can, in regard to motor abilities, catch-up with healthy children as a result of sensorimotor therapy. (f) Has begun the work on formulating a new theoretical framework for grounded assessments and interventions.

3.5.2 What have I learned from this long journey?

The work accomplished would never have been possible without the sharing of thoughts and experiences with my dear wife Irene. A job like ours cannot be left at 4 in the afternoon and to be started again at 9 the next day. The development of the children and the lives of the families are always thought provoking. Much of a day's work is then confidentially discussed between Irene and me during dinner or during walks. We have had some resistance over the years, especially from the health service, which unfortunately may have had difficulties in acquiring new perspectives. But I think we have done well not the least since we have constantly been seeking scientific support. The work has taught me to trust my own ability in order to follow the path I have found to be right. The work has also taught me to look long term and to be persistent, not to give up even though it has sometimes been close at hand. This applies to both the work with the children and to the academic process. The fact that I did not give up the scientific work has mainly two reasons. One reason is Professor Norlander's support during the process and his own conviction that our work can benefit the children of the future. A second reason is that the work taught me that anecdotal stories of progress are not counted at all if you want to make a difference. All that counts are published results. Since I have experienced how many children exhibit sensorimotor problems as well as their parents not being taken seriously when shown concern, it feels even more important that our work is not silenced. The development and practice of Retraining for Balance must be tested and documented in order to later be a recognized complement to existing treatment of both DCD and ADHD. The work has given me not only an increased understanding of people's differences, but also an increased understanding that children, young people and adults have a potential that can be brought about through training. Without being overly pretentious, I still want to claim that the work has shaped me as a person and made me more humble in the face of life's various difficulties.

4. CONCLUSIONS

The overarching purpose of this Thesis has been to evaluate assessments and interventions for sensorimotor therapy according to the method Retraining for Balance. The empirical studies included have indicated a scenario in which re-activation and integration of arrested primary reflexes together with vestibular stimulation caused regressions, which was shown to be prerequisites for the emergence and release of both physiological and psychological transformations. The results elucidate not only the importance of a grounded approach concerning assessments and interventions in regard to DCD, but also the matter of parents (or spouses) help and guidance during training, as well as the matter of gravity and its influence on the vestibular system. These observations led us to propose a Brain-Body-World Interaction (BBWI) perspective including both horizontal and vertical connections as a starting point for a new theoretical framework regarding DCD. The horizontal connection is often discussed which implies our being in the world with all possible interactions with family and friends. In existing literature about neuropsychiatric disorders the vertical connection to the vestibular system has so far received much less attention.

5. REFERENCES

Adolph, K. E., Weise, I., & Marin, L. (2003). Motor development. In L. R. Nadel (Ed.), *Encyclopedia of cognitive science* (Vol.3, pp. 134-137). London: Nature Publishing Group.

Ahonen, T., Kooistra, L., Viholainen, H., & Cantell, M. (2004). Developmental motor learning disability. A neuropsychological approach. In D. Dewey & D. E. Tupper (Eds.), *Developmental motor disorders. A neuropsychological perspective* (pp. 265-290). New York, NY: The Guilford Press.

American Psychiatric Association (1994). *Diagnostic and statistical manual of mental disorders*, (4th ed). Washington, DC: American Psychiatric Association, 53-55.

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders*. (5th ed.). Arlington, VA: American Psychiatric Association, 74-77.

Anastasi, A., & Urbina, S. (2007). *Psychological testing* (pp. 33-34). New Delhi, India: Prentice-Hall.

Andrich, P., Shihada, M. B., Vinci, M. K., Wrenhaven, S. L., & Goodman, G. D. (2018). Statistical relationships between visual skill deficits and retained primitive reflexes in children. *Optometry & Visual Performance*, *6,* 106-111.

Aristotle (1992). *Introduction to Aristotle* (pp. 151-254). Edited, with introductions, by Richard McKeon. New York, NY: Random House Inc.

Aubert, S., Barnes, J. D., Abdeta, C., Abi Nader, P., Adeniyi, A. F., Aguilar-Farias, N., ... & Tremblay, M. S. (2018). Global matrix 3.0 physical activity report card grades for children and youth: Results and analysis from 49 countries. *Journal of Physical Activity and Health, 15* (Supplement 2), S251-S273.

Ayd Jr, F. J. (2000). *Lexicon of psychiatry, neurology, and the neurosciences* (p. 686). Philadelphia, PA: Lippincott Williams & Wilkins.

Ayres, A. J. (1973). *Sensory integration and learning disorders*. Los Angeles, CA: Western Psychological Services.

Ayres, A. J., & Robbins, J. (2005). *Sensory integration and the child. Understanding hidden sensory challenges*. 25th anniversary edition (p. 69). Los Angeles, CA: Western Psychological Services.

Balint, M. (1968). *The basic fault. Therapeutic aspects of regression* (pp. 131, 154). Evanstone, IL: Northwestern University Press.

Battegay, R. (1970). Regressionsphänomene aus klinischer sicht unter besonderer berücksichtigung analytischer kurzpsychotherapie [Regression phenomena from the clinical viewpoint, with special consideration of analytic short therapy]. *Praxis der Psychotherapie, 15,* 151-162.

Bergman, A., & Norlander, T. (2005). ”Hay sacks anonymous”: Living in the shadow of the unidentified. Psychological aspects of physical inactivity from a phenomenological perspective. *The Qualitative Report, 10,* 795-816.

Bergström, R. A. M. (1963). On the physiology of the meso-diencephalic extrapyramidal system, with special reference to the pathogenesis of involuntary movements. *Acta Neurologica Scandinavica, 39,* 52-60.

Bergström, R. M. (1964). Über das Wahrnehmen der Zeit als Wahrnehmen der Bewegung. [About the perception of time as perception of movement]. *Annals Academiae Scientiarum Fennicae*. Series A. 106, 2.

Bergström, R. M. (1969). An entropy model of developing brain. *Developmental Psychobiology, 2,* 139-152.

Bergström, M. (1989). Meaning and the living brain. In P. Pylkkänen (Ed.), *The search for meaning. The new spirit in science and philosophy* (pp. 124-154). Wellingborough, UK: Crucible.

Bergström, M., Niklasson, M., & Niklasson, I. (1999). *Reason for Training.* Mönsterås, Sweden: Vestibularis.

Berthoz, A. (2000). *The brain's sense of movement* (pp. 57-58). Cambridge, MA: Harvard University Press.

Berthoz, A. (2012). *Simplexity. Simplifying principles for a complex world* (p. 131). New Haven, CT: Yale University Press.

Bertolero, M., & Bassett, D. S. (2019). How matter becomes mind. *Scientific American, 321*(1), 18-25.

Besnard, S., Lopez, C., Brandt, T., Denise, P., & Smith, P. F. (2015). Editorial: The vestibular system in cognitive and memory process in mammalians. *Frontiers in Integrative Neuroscience, 9*: 55.

Blank, R., Barnett, A. L., Cairney, J., Green, D., Kirby, A., Polatajko, H., ... & Vinçon, S. (2019). International clinical practice recommendations on the definition, diagnosis, assessment, intervention, and psychosocial aspects of developmental coordination disorder. *Developmental Medicine & Child Neurology, 61,* 242–285.

Blythe, P. (1990). *The History of the Institute for Neuro-Physiological Psychology (INPP)*. Chester, UK: INPP.

Blythe, P. (2009). Development of the INPP method-from theory to fact. In S. Goddard Blythe (Ed.) *Attention, Balance and Coordination. The A.B.C. of Learning Success* (pp. 311-323). Chichester, UK: Wiley-Blackwell.

Blythe, P., & McGlown, D. J. (1979). *An organic basis for neuroses and educational difficulties. A new look at the old Minimal Brain Dysfunction syndrome*. Chester, UK: Insight Publications.

Bonney, E., & Smits-Engelsman, B. (2019). Movement skill assessment in children: Overview and recommendations for research and practice. *Current Developmental Disorders Reports, 6,* 67-77.

Braswell, J., & Rine, R. M. (2006). Evidence that vestibular hypofunction affects reading acuity in children. *International Journal of Pediatric Otorhinolaryngology*, *70*, 1957-1965.

Briggs, J., & Peat, F. D. (1990). *Turbulent mirror* (pp. 134-152, 168-170). New York, NY: Harper & Row, Publishers, Inc.

Bromberg, W. (1982). *Psychiatry between the wars, 1918-1945. A recollection* (p. 60). Westport, CT: Greenwood Press.

Burman, B. (1977). *Keystone visual skills test.* Malmö, Sweden: All-Optik.

Butterworth, G., & Harris, M. (1998). *Principles of Developmental Psychology* (p. 20). Hove, UK: Psychology Press Ltd, Publishers.

Caçola, P. (2016). Physical and mental health of children with developmental coordination disorder. *Frontiers in Public Health, 4:* 224.

Caçola, P., & Lage, G. (2019). Developmental Coordination Disorder (DCD): An overview of the condition and research evidence. *Motriz: Revista de Educação Física, 25* (2): https://dx.doi.org/10.1590/s1980-6574201900020001.

Cairney J. (2015). Developmental coordination disorder and its consequences: An introduction to the problem. In: J. Cairney (Ed.), *Developmental coordination disorder and its consequences* (pp. 5–30). Toronto: University of Toronto Press.

Cairney, J., Hay, J. A., Wade, T. J., Faught, B. E., & Flouris, A. (2006). Developmental coordination disorder and aerobic fitness: Is it all in their heads or is measurement still the problem? *American Journal of Human Biology, 18,* 66-70.

Cairney, J., Veldhuizen, S., & Szatmari, P. (2010). Motor coordination and emotional-behavioral problems in children. *Current Opinion in Psychiatry 23,* 324-329.
Cairney, J., Rigoli, D., & Piek, J. (2013). Developmental coordination disorder and internalizing problems in children: The environmental stress hypothesis elaborated. *Developmental Review, 3,* 224-238.
Capute, A. J., Accardo, P. J., Vining, E. P. G., Rubenstein, J. E., & Harryman, S. (1978). *Primitive reflex profile*. Baltimore, MD: University Park Press.
Capute, A. J., & Accardo, P. J. (1991). *Developmental disabilities in infancy and childhood* (pp. 20-21, 341). Baltimore, MD: Paul H. Brookes Co., Inc.
Casaer, P. (1993). Development of motor functions: A 'developmental neurological' approach. In A. F. Kalverboer, B. Hopkins, & R. Geuze (Eds.), *Motor development in early and later childhood: Longitudinal approaches* (pp. 125-135). Cambridge: Cambridge University Press.
Charman, W. N. (2008). The eye in focus: Accommodation and presbyopia. *Clinical and Experimental Optometry, 91,* 207-225.
Crutchfield, C. A., & Barnes, M. R. (1993). *Motor control and motor learning in rehabilitation.* (p. 152). Atlanta, GA: Stokesville Publishing Company.
Chiel, H. J., & Beer, R. D. (1997). The brain has a body: Adaptive behavior emerges from interactions of nervous system, body and environment. *Trends in Neurosciences, 20,* 553-557.
Cianfrani, C. A., & West, J. E. (2017). *Cracking the case of ISO 9001:2015 for manufacturing*. Milwaukee, WI: ASQ Quality Press.
Clark, A. (1997). *Being there: Putting brain, body and world together*. Cambridge, MA: The MIT Press.
Clark, A. (1999). An embodied cognitive science? *Trends in Cognitive Sciences, 3,* 345-351.
Clark, A. (2016). *Surfing uncertainty. Prediction, action and the embodied mind* (pp. 249-250, 297). Oxford: Oxford University Press.
Clark, B. R., Randle, R. J., & Stewart, J. D. (1975). Vestibular-ocular accommodation reflex in man. *Aviation Space and Environmental medicine, 46,* 1336-1339.
Clarke, E., & Jacyna, L. S. (1987). *Nineteenth – century origins of neuroscientific concepts* (pp. 101-156). Berkeley, CA: University of California Press, Ltd.
Cogan, D. G. (1972). *Neurology of the ocular muscles* (pp. 184-229). Springfield, IL: Charles C. Thomas Publisher.
Cohen, B., & Lewis, R. (2018). Editorial: Vestibular contributions to health and disease. *Frontiers in Neurology, 9*: 117.
Conners, C. K. (1990). *Conners' rating scales manual, Conners' teacher rating scales, Conners' parents rating scales. Instruments for use with children and adolescents.* North Tonawanda, NY: MultiHealth Systems.
Coren, S., & Porac, C. (1975). The myth of the normal eye: A methodological note. *Bullentin of the Psychonomic Society, 5,* 469-470.
Cruickshank, W. M. (1981). A new perspective in teacher education: The neuroeducator. *Journal of Learning Disabilities, 14,* 337-341, 367.
Dennis, W. (1935). A psychologic interpretation of the persistence of the so-called Moro reflex. *The American Journal of Diseases of Children, 50,* 888-893.
Dennis, M., Spiegler, B. J., Juranek, J. J., Bigler, E. D., Snead, O. C., & Fletcher, J. M. (2013). Age, plasticity, and homeostasis in childhood brain disorders. *Neuroscience & Biobehavioral Reviews, 37,* 2760-2773.
Desai, S. S., & Dua, A. (2014). History of research in the vestibular system: A 400-year-old story. *Anatomy & Physiology: Current Research, 4,* 138-43.

Dotov, D. G. (2014). Putting reins on the brain. How the body and environment use it. *Frontiers in Human Neuroscience, 8:* 795.

Edebol, H., Helldin, L., & Norlander, T. (2012). Objective measures of behavior manifestations in adult ADHD and differentiation from bipolar II disorder, borderline personality disorder, participants with disconfirmed ADHD as well as and normative participants. *Clinical Practice & Epidemiology in Mental Health, 8,* 134-143.

Eliot, L. (2000). *What's going on in there? How the brain and mind develop in the first five years of life* (p. 151). New York, NY: Bantam.

Enander, J. M. D., Spanne, A., Mazzoni, A., Bengtsson, F., Oddo, C. M., & Jörntell, H. (2019). Ubiquitous neocortical decoding of tactile input patterns. *Frontiers in Cellular Neuroscience, 13:* 140.

Esparham, A., Evans, R. G., Wagner, L. E., & Drisko, J. A. (2014). Pediatric integrative medicine approaches to attention deficit hyperactivity disorder (ADHD). *Children, 1,* 186-207.

Faught, B. E., Hay, J. A., Carney, J., & Flouris, A. (2005). Increased risk for coronary vascular disease in children with developmental coordination disorder. *The Journal for Adolescent Health*, *37*, 376-380.

Feigenberg, J. M. (2004). *Nicolai Bernstein. From reflex to the model of the future*. Zürich, Schweiz: LIT Verlag.

Feldman Barrett, L. (2009). The future of psychology: Connecting mind to brain. *Perspectives on Psychological Science, 4,* 326-339.

Feldman Barrett, L. (2014). The conceptual act theory: A précis. *Emotion Review, 6,* 292-297.

Feldman Barrett, L. (2017). The theory of constructed emotion: An active inference account of interoception and categorization. *Social Cognitive Affective Neuroscience, 12*, 1-23.

Feldman Barrett, L., Quigley, K. S., & Hamilton, P. (2016). An active inference theory of allostasis and interoception in depression. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 19:* 371.

Field, J., & Blythe, P. (1989). *Towards developmental re-education*. Wichenford, UK: Field Educational Publishing.

Finger, S. (1994). *Origins of neuroscience* (pp. 18-19). Oxford: Oxford University Press.

Fiorentino, M. R. (1981). *Reflex testing methods for evaluating C.N.S. development*, 2nd ed. (Publ. No. 865). Springfield, IL: Charles C. Thomas Publisher.

Flugel, J. C. (1933). *A hundred years of psychology* (p. 55). London: Duckworth.

Frede, D. (1995). The cognitive role of *Phantasia* in Aristotle. In M. C. Nussbaum & A. Oksenberg Rorty (Eds.), *Essays on Aristotle's De Anima* (pp. 283-284). Oxford: Oxford University Press.

Frick, A., & Möhring, W. (2016). A matter of balance: Motor control is related to children's spatial and proportional reasoning skills. *Frontiers in Psychology, 6:* 2049.

Fuchs, D. (2018). Dancing with Gravity—Why the Sense of Balance Is (the) Fundamental. *Behavioral Sciences, 5*: 8.

Gesell, A. (1945/1988). *The embryology of behavior. The beginning of the human mind* (p. 187), (Classics in developmental medicine No 3). London: Mac Keith Press.

Gilfoyle, E. M., Grady, A. P., & Moore, J. C. (1990). *Children apt* (pp. 13-32). Thorofare, NJ: SLACK Incorporated.

Gillberg, C. (1991). Nordisk enighet om MBD-bedömning. Termen otidsenlig och olämplig [A Nordic consensus concerning MBD assessment: The denomination is old-fashioned and unsuitable]. *Läkartidningen, 88*, 713-717.

Gillberg, C. (2003). Deficits in attention, motor control, and perception: A brief review. *Archives of Disease in Childhood*, *88*, 904-910.

Gillberg, C. (2017). Developmental coordination disorder. Retrieved from http://gillbergcentre.gu.se/english/research/diagnoses--methods-and-ongoing-studies-at-gnc/developmental-coordination-disorder--dcd- 20190511.

Gillberg, C., Kadesjö, B. (2009). ADHD with developmental coordination disorder (pp. 305-314). In T. E. Brown (Ed.), *ADHD Comorbidities. Handbook for ADHD complications in children and adults*. Arlington, VA: American Psychiatric Publishing, Inc.

Gillberg, C., Rasmussen, P. (2003). Editorial: To what extent are learning and behavioural problems brain related? *Acta Psychiatrica Scandinavica, 108,* 81-82.

Goddard, S. (1990). *A developmental basis for learning difficulties and language disorders*. INPP Monograph Series 1. Chester, UK: INPP.

Goddard, S. (2002). *Reflexes, learning and behavior. A window into a child's mind* (p. 101). Eugene, OR: Fern Ridge Press.

Goddard Blythe, S. (2009). *Attention, balance, and coordination. The A.B.C. of learning success* (pp. 101-102). Chichester, UK: John Wiley & Sons Ltd.

Goldfield, E. C., & Wolff, P. H. (2004). A dynamic systems perspective on infant action and its development. In G. Bremner, & A. Slater (Eds.), *Theories of infant development* (pp. 3-29). Oxford, UK: Blackwell Publishing Ltd.

Gordon, M. B. (1929). The Moro embrace reflex in infancy. Its incidence and significance. *The American Journal of Diseases of Children, 38,* 26-34.

Gottlieb, G., Wahlsten, D., & Lickliter, R. (2006). The significance of biology for human development: A developmental psychobiological systems view. In R. M. Lerner (Ed.), *Handbook of Child Psychology, volume 1. Theoretical models of human development* (p. 213). Hoboken, NJ: John Wiley & Sons Inc.

Goyette, C. H., Conners, C. K., & Ulrich, R. F. (1978). Normative data on revised Conners Parent and Teacher Rating Scales, *Journal of Abnormal Child Psychology, 6*, 221-236.

Grillon, C., Pine, D. S., Baas, J. M. P, Lawley, M., Ellis, V., & Charney, D. S. (2006). Cortisol and DHEA-S are associated with startle potentiation during aversive conditioning in humans. *Psychopharmacology, 186,* 434-441.

Guenther, K. (2015). *Localization and its discontents. A genealogy of psychoanalysis and the neuro disciplines*. Chicago, IL: The University of Chicago Press.

Guttman, S. A. (1960). Panel Reports – Criteria for Analyzability. *Journal of American Psychoanalytic Association*, *8*, 141-151.

Guyton, A. C. (1991). *Basic neuroscience: Anatomy and physiology* (pp. 216-223). Philadelphia, PA: W. B. Saunders Company.

Helldin, L., Kane, J. M., Karilampi, U., Norlander, T., & Archer, T. (2006). Remission and cognitive ability in a cohort of patients with schizophrenia. *Journal of Psychiatric Research, 40,* 738-745.

Helldin, L., Kane, J., Karilampi, U., Norlander, T., & Archer, T. (2007). Remission in prognosis of functional outcome: A new dimension in the treatment of patients with psychotic disorders. *Schizophrenia Research, 93,* 160-168.

Helldin, L., Kane, J.M., Hjärthag, F., & Norlander, T. (2009). The importance of cross-sectional remission in schizophrenia for long-term outcome: A clinical prospective study. *Schizophrenia Research, 115,* 67-73.

Hillier, S. (2007). Intervention for children with developmental coordination disorder: A systematic review. *The Internet Journal of Allied Health Sciences and Practice*, *5*(3), 1-11. Retrieved from http://ijahsp.nova.edu 2019 09 12.

Hoogman, M., Bralten, J., Hibar, D. P., Mennes, M., Zwiers, M. P., Schweren, L. S. J., ... & Franke, B. (2017). Subcortical brain volume differences in participants with attention deficit hyperactivity disorder in children and adults: A cross-sectional mega-analysis. *The Lancet Psychiatry, 4*, 310-319.

Holle, B. (1981). *Motor development in children: Normal and retarded: A practical guide for sensory motor stimulation.* Oxford: Blackwell Scientific.

Holt, K. S. (1991). *Child development: Diagnosis and assessment*. London: Butterworth-Heinemann.

Howes, D. (2009). Introduction. The revolving sensorium. In D. Howes (Ed.), *The sixth sense reader* (pp. 1-52). Oxford: Berg.

Hraste, M., De Giorgio, A., Mandic´Jelaska, P., Padulo, J., & Granic´, I. (2018). When mathematics meets physical activity in the school-aged child: The effect of an integrated motor and cognitive approach to learning geometry. *PLoS ONE*, *13,* (8):e0196024.

Hubbard, D. G. (1971). *The skyjacker. His flights of fantasy* (pp. 68-74). New York, NY: The Macmillan Company.

Hubbard, D. G., & Wright, C. G. (1984). The emotion of motion. Functions of the Vestibular apparatus. In D. A Shaskan, & W. L. Roller (Eds.), *Paul Schilder. Mind explorer* (pp. 161-182). New York, NY: Human Sciences Press.

Humphrey, G. (1962). Introduction. In J. M. G. Itard (Author), *The wild boy of Aveyron* (pp. v-xxiv). Englewood Cliffs, NJ: Prentice Hall, Inc.

Humphrey, T. (1965). The embryologic differentiation of the vestibular nuclei in man correlated with functional development (pp. 51-56). In I. Kirikae (Ed.), *Vestibular and oculomotor problems: Extraordinary meeting of the Japan society of vestibular research*. Tokyo: University of Tokyo.

Hydén, H. (1961). Biochemical aspects of brain activity. In S. Farger, & R. Wilson (Eds.), *Man and civilization: Control of the mind* (pp. 18-41). New York, NY: McGraw-Hill.

Illingworth, R. S. (1987). *The development of the infant and young child: Normal and abnormal* (pp. 1, 81). London: Churchill Livingstone.

Ingram, T. T. S. (1973). Soft signs. *Developmental Medicine & Child Neurology*, *15*, 527-530.

Ingster-Moati, I., Vaivre-Douret, L., Bui Quoc, E., Albuisson, E., Dufier, J. L., & Golse, B. (2009). Vertical and horizontal smooth pursuit eye movements in children: A neuro-developmental study. *European Journal of Paediatric Neurology*, *13*, 362-366.

IPLA (International Physical Literacy Association) (2017). https://www.physical-literacy.org.uk/

Itard, J. M. G. (1801/1962). *The wild boy of Aveyron.* Englewood Cliffs, NJ: Prentice Hall, Inc.

Jacobs, L., & Gossman, M. D. (1980). Three primitive reflexes in normal adults. *Neurology*, *30*, 184-188.

Jamon, M. (2014). The development of vestibular system and related functions in mammals: Impact of gravity. *Frontiers in Integrative Neuroscience, 8:* 11.

Janols, L. O., & von Knorring, A. L. (1991). Är medikamentell behandling motiverad vid hyperaktivitet hos barn? [Is stimulant drug action motivated when the child is hyperactive?]. *Läkartidningen 88*, 3057-3058, 3061.

Johansen, K. V. (1993). *Lyd, hørelse og sprogudvikling.* [*Sound, hearing and the development of language*]. Horsens, Denmark: Forlaget Aalokke a/s.

Johnston, M. V. (2009). Plasticity in the developing brain: Implication for rehabilitation. *Developmental Disabilities Research Reviews, 15,* 94-101.

Jeannerod, M. (1985). *The brain machine. The development of neurophysiological thought*. Cambridge, MA: Harvard University Press.

Kamm, K., Thelen, E., & Jensen, J. L. (1990) A dynamical systems approach to motor development. *Physical Therapy*, *70*, 763-775.

Kandel, E. R. (2005). Psychiatry, psychoanalysis and the new biology of mind (p. 80). Washington, DC: American Psychiatric Publishing, Inc.
Karlsson, G. (1995). *Psychological qualitative research*. Stockholm: Almquist & Wiksell.
Kestenberg, J. S., & Sossin, K. M. (1979). *The role of movement patterns in development 2* (p. 94). New York, NY: Dance Notion Bureau Press.
Kirby, A. (2004). Editorial: Is dyspraxia a medical condition or a social disorder? *British Journal of General Practice*, *54*, 6-8.
Kirby, A., Salmon, G., & Edwards, L. (2007). Attention deficit hyperactivity and developmental coordination disorders: Knowledge and practice among child and adolescent psychiatrists and paediatricians. *Psychiatric Bulletin, 31,* 336-338.
Klosovskii, B. N. (1963). *The development of the brain and its disturbance by harmful factors* (pp. 106-121). New York, NY: The Macmillan Company.
Khouja, J. N., Munafò, M. R., Tilling, K., Wiles, N. J., Joinson, C., Etchells, P. J., ... & Cornish, R. P. (2019). Is screen time associated with anxiety or depression in young people? Results from a UK birth cohort. *BMC Public Health*, *19,* 82.
Knafo, D. (2002). Revisiting Ernst Kris's concept of regression in the service of the ego in art. *Psychoanalytic Psychology, 19,* 24-49.
Kris, E. (1952). *Psychoanalytic explorations in art* (pp. 177-178). New York, NY: International Universities Press, Inc.
Kroeber, T. C. (1963). The coping functions of the ego mechanisms. In R.W. White (Ed.), *The study of lives: Essays on personality in honour of Henry A. Murray* (p. 187). New York, NY: Atherton Press.
Laszlo, E. (1993). *The creative cosmos. A unified science of matter, life and mind* (pp. 56-60). Edinburgh: Floris Books.
Larsen, W. J. (1993). *Human embryology* (pp. 382-383). London: Churchill Livingstone.
Leibnitz, G. W. (1765/1997). *New essays on human understanding* (sections 53-56). Cambridge, UK: Cambridge University Press.
Liddell, E. G. T. (1960). *The discovery of reflexes*. Oxford: Oxford University Press.
Llinás, R. R. (2002). *I of the vortex. From neurons to self* (pp. 127-128). Cambridge, MA: The MIT Press.
Loewald, H. W. (1978). *Psychoanalysis and history of the individual* (p. 22). New Haven, CT: Yale University Press.
Loewald, H. W. (1981). Regression: Some general considerations. *Psychoanalytic Quaterly*, *50,* 22-43.
Lokko, H. N., & Stern, T. A. (2015). Regression: Diagnosis, evaluation, and management. *Primary Care Companion for CNS Disorders*, *17* (3): 10.4088/PCC.14f01761.
Mahoney, G., Robinson, C., & Perales, F. (2004). Early motor intervention: The need for new treatment paradigms. *Infants and Young Children, 17,* 291-300.
Maurer, D., & Maurer, C. (1989). *The world of the newborn* (pp. 165-168). London: Viking.
McGraw, M. B. (1945/1989). *The neuromuscular maturation of the human infant* (p. 60), (Classics in developmental medicine No 4). London: Mac Keith Press.
McGraw, M. B. (1935/1995). General principles of growth. In T. C. Dalton & V. W. Bergenn (Eds.), *Beyond heredity and environment: Myrtle McGraw and the maturation controversy* (pp. 177-186). Boulder, CO: Westview Press.
McPhillips, M., Hepper, P. G., & Mulhem, G. (2000). Effects of replicating primary-reflex movements on specific reading difficulties in children: A randomised, double blind, controlled trial. *The Lancet*, *355*, 537-541.
Mehler, J., & Dupoux, E. (1994). *What infants know. The new cognitive science of early development* (pp. 39-47). Oxford: Blackwell Publishers.

Mitchell, A. J. (2003). *Neuropsychiatry and behavioural neurology explained: Diseases, diagnosis, and management* (p. 33). Philadelphia, PA: Saunders.
Morris, D. (1991). *Babywatching* (pp. 136-137). London, UK: Jonathan Cape.
Morrison, D. C. (1985). *Neurobehavioral and perceptual dysfunction in learning disabled children* (p. 13). Lewiston, NY: C. J. Hogrefe, Inc.
Moser, M. B., & Moser, E. I. (2016). Where am I? Where am I going? *Scientific American*, *314*(1)*,* 26-33.
Moser, I., Vibert, D., Caversaccio, M. D., & Mast, F. W. (2017). Impaired math achievement in patients with acute vestibular neuritis. *Neuropsychologia*, *107*, 1-8.
Mualem, R., Leisman, G., Zbedat, Y., … & Ornai, A. (2018). The effect of movement on cognitive performance. *Frontiers in Public Health 6*: 100.
Nicolis, G. (1993). Physics of far-from-equilibrium systems and self-organisation. In P. Davies (Ed.), *The new physics* (p. 330). Cambridge, MA: Cambridge University Press.
Nierenberg, A. A. (2019). What's our brain anyway? *Psychiatric Annals*, *49*, 43.
Niklasson, M. (2013). *Sensorimotor therapy: Assessing quantitative and qualitative expressions of physiological and psychological development in children*. Unpublished licentiate thesis, Faculty of Arts and Social Sciences, Karlstad University, Sweden.
Niklasson, M., Hector, K. G. (1989). *Ett försök att utvärdera effecter av motorisk träning* [*An attempt to evaluate effects from motor training*]. The University College in Kalmar, Department for teacher training, Report D 1989:4.
Niklasson, M., & Niklasson, I. (1999a). *Retraining for Balance-Physiological Test*. Mönsterås, Sweden: Vestibularis.
Niklasson, M., & Niklasson, I. (1999b). *Retraining for Balance-Orientation and Balance Test*. Mönsterås, Sweden: Vestibularis.
Niklasson, M., & Niklasson, I. (2007a). *Retraining for Balance-Physiological Test Revised*. Mönsterås, Sweden: Vestibularis.
Niklasson, M., & Niklasson, I. (2007b). *Retraining for Balance- Orientation and Balance Test Revised*. Mönsterås, Sweden: Vestibularis.
Niklasson, M., & Niklasson, I., & Bergström, M. (1999). *Retraining for Balance-Methods*. Mönsterås, Sweden: Vestibularis.
Niklasson, M., & Niklasson, I., & Bergström, M. (2007). *Retraining for Balance-Methods Revised*. Mönsterås, Sweden: Vestibularis.
Niklasson, M., Niklasson, I., & Norlander, T. (2009). Sensorimotor therapy: Using stereotypic movements and vestibular stimulation to increase sensorimotor proficiency of children with attentional and motor difficulties. *Perceptual and Motor Skills, 108,* 643-669. (**Paper I**)
Niklasson, M., Niklasson, I., & Norlander, T. (2010). Sensorimotor therapy: Physical and psychological regressions contribute to an improved kinesthetic and vestibular capacity in children and adolescents with motor difficulties and concentration problems. *Social Behavior and Personality, 38,* 327-346. (**Paper II**)
Niklasson, M., Rasmussen, P., Niklasson, I., & Norlander, T. (2015). Adults with sensorimotor disorders: Enhanced physiological and psychological development following specific sensorimotor training. *Frontiers in Psychology, 6:* 480. (**Paper III**)
Niklasson, M., Norlander, T., Niklasson, I., & Rasmussen, P. (2017). Catching-up: Children with developmental coordination disorder compared to healthy children before and after sensorimotor therapy. *PLoS ONE, 12,*(10):e0186126. (**Paper IV**)
Niklasson, M., Rasmussen, P., Niklasson, I., & Norlander, T. (2018). Developmental coordination disorder: The importance of grounded assessments and interventions. *Frontiers in Psychology, 9:* 2409. (**Paper V**)

Nilsson Benfatto, M., Öqvist Seimyr, G., Ygge, J., Pansell, T., Rydberg, A., & Jacobson, C. (2016). Screening for dyslexia using eye tracking during reading. *PLoS ONE, 11,*(12): e0165508.

Nissen, G. (2005). *Kulturgeschichte seelischer Störungen bei Kindern und Jungenlichen* (pp. 82-185). Stuttgart: Klett-Cotta.

Norlander, T., Moås, L., & Archer, T. (2005). Noise and stress in primary and secondary school children: Noise reduction and increased concentration ability through a short but regularly exercise and relaxation program. *School Effectiveness and School Improvement, 16,* 91-99.

Norlander, T., Ernestad, E., Moradiani, Z., & Nordén, T. (2015). Perceived feeling of security: A candidate for assessing remission in borderline patients? *The Open Psychology Journal*, *8*, 146-152.

Odent, M. (1986). *Primal health. A blueprint for our survival* (pp. 18-30). London: Century Hutchinson Ltd.

Okamoto, H., Stracke, H., Ross, B., Kakigi, R., & Pantev, C. (2007). Left hemispheric dominance during auditory processing in noisy environment. *BMC Biology*, *5*: 52.

Ornitz, E. M. (1983). Normal and pathological maturation of vestibular function in the human child. In R. Romand (Ed.), *Development of auditory and vestibular systems* (pp. 479-536). New York, NY: Academic Press, Inc.

Parr, J. R. (2017). Does developmental regression in autism spectrum disorder have biological origins? *Developmental Medicine & Child Neurology*, *59*, 889.

Paulson, G., Gottlieb, G. (1968). Development reflexes: The reappearance of foetal and neonatal reflexes in aged patients. *Brain*, *91*, 37-52.

Pennigton, B. F. (2009). *Diagnosing learning disorder. A neurological framework* (pp. 227-233). New York, NY: The Guilford Press.

Piontelli, A. (2015). *Development of normal fetal movements. The last 15 weeks of gestation* (pp. 119-121). Milan: Springer.

Polatajko, H. J. (1999). Developmental Coordination Disorder (DCD): Alias, the clumsy child syndrome. In K. Whitmore, H. Hart, & G. Willems (Eds.), *A neurodevelopmental approach to specific learning disorders* (pp. 119-133). London: Mac Keith Press.

Prechtl, H. F. R. (1977). *The neurological examination of the full-term newborn infant*. London: Spastics International Medical Publications.

Prechtl, H. F. R. (1984). Continuity and change in early neural development. In H. F. R Prechtl (Ed.), *Continuity of neural functions from prenatal to postnatal life* (pp. 1-15). Oxford: Spastics International Medical Publications.

Prechtl, H.F.R. (1993). Principles of early motor development in the human. In A. Kalverboer, B. Hopkins, & R. Geuze (Eds.), *Motor development in early and later childhood: Longitudinal approaches* (pp. 35-50). Cambridge: Cambridge University Press.

Preyer, W. (1882/1923). *Die Seele des Kindes* [*The Soul of the Child*] (pp. 121-133). Leipzig: Th. Griebens Verlag.

Prigogine, I. (2003). *Is future given?* (pp. 67-69). River Edge, NJ: World Scientific Publishing Co. Pte. Ltd.

Prigogine, I., & Stengers, I. (1984). *Order out of Chaos. Man's new dialogue with nature* (pp. 160-176). London: William Heinemann LTD.

Quatman-Yates, C. C, Quatman, C. E., Meszaros, A. J., Paterno, M. V., & Hewett, T. E. (2012). A systematic review of sensorimotor function during adolescence: A developmental stage of increased motor awkwardness? *British Journal of Sports Medicine*, *46*, 649-655.

Rasmussen, P., Gillberg, C. (2000). Natural outcome of ADHD with developmental coordination disorder at age 22 years: A controlled, longitudinal, community-based study. *Journal of the American Academy of Child and Adolescent Psychiatry*, *39*, 1424-1431.

Restak, R. M. (1979). *The brain. The last frontier* (p. 122). New York, NY: Warner Books.

Richardson, F. H., & Johnson Hearn, W. (1930). *The pre-school child and his posture.* New York, NY: G.P. Putnam's sons.

Rider, B. A. (1972). Tonic neck reflexes. *The American Journal of Occupational Therapy, 26*, 132-134.

Rine, R. M. (2009). Growing evidence for balance and vestibular problems in children. *Audiological Medicine 7*, 138-142.

Riskin, J. (2009). The Mesmerism investigation and the crisis of sensationist science. In D. Howes (Ed.), *The sixth sense reader* (pp. 119-149). Oxford: Berg.

Robbins, J. (1977). Vestibular integration. Man's connection to the earth. *Somatics*, *1,* 27-36.

Robert, M. P., Ingster-Moati, I., Albuisson, E., Cabrol, D., Golse, B., & Vaivre-Douret, L. (2014). Vertical and horizontal smooth pursuit eye movements in children with developmental coordination disorder. *Developmental Medicine & Child Neurology*, *56*, 595-600.

Rochat, P. (2001). *The infant's world* (p. 227). Cambridge, MA: Harvard University Press.

Ronca, A. E., & Alberts, J. R. (2000). Effects of prenatal spaceflight on vestibular responses in neonatal rats. *Journal of Applied Physiology*, *89*, 2318-2324.

Santrock, J. W. (2011). *Life-span development* (pp. 125-131). New York, NY: McGraw-Hill International Edition.

Schilder, P. (1942/1971). *Mind: Perception and thought in their constructive aspects* (p. 85). Freeport, NY: Books for Libraries Press.

Schilder, P. (1964). *Contributions to developmental neuropsychiatry* (pp. 161-209). New York, NY: International Universities Press, Inc.

Schoemaker, M. M., & Wilson, B. N. (2015) Screening for developmental coordination disorder in school-age children. In J. Cairney (Ed.), *Developmental coordination disorder and its consequences* (pp. 169-191). Toronto: University of Toronto Press.

Scott, O., Shi, D., Andriashek, D., Clark, B., & Goez, H. R. (2017). Clinical clues for autoimmunity and neuroinflammation in patients with autistic regression. *Developmental Medicine & Child Neurology*, *59*, 947-951.

Schwartz, F. (1981). Psychic structure. *The International Journal of Psychoanalysis*, *62*, 61-72.

Séguin, E. (1907/2009). *Idiocy and its treatment by the physiological method*. Ithaca, NY: Cornell University Library.

Sharot, T. (2011). The optimism bias. *Current Biology*, *21*, R941-R945.

Sininger, Y. S., & Cone-Wesson, B. (2004). Asymmetric cochlear processing mimics hemispheric specialization. *Science*, *305*, 1581.

Sloane, A. E., & Rosenthal, P. (1960). School vision testing. *Transactions of the American Ophthalmological Society, 58*, 43-58

Smith, P. F. (2012). Dyscalculia and vestibular function. *Medical Hypotheses, 79*, 493-496.

Smits-Engelsman, B. C. M, Blank, R., van der Kaay, A. C., Mosterd-van der Meijs, R., Vlugt-van den Brand, E., Polatajko, H. J., & Wilson, P. H. (2013). Efficacy of interventions to improve motor performance in children with developmental coordination disorder: A combined systematic review and meta-analysis. *Developmental Medicine & Child Neurology, 55*, 229–237.

Spencer H. (1855). *The principles of psychology*. London: Longman, Brown, Green & Longmans.
Sreekantam, S., & Wassmer, E. (2013). An approach to developmental regression. *Paediatrics and Child Health*, *23*, 273-277.
Stanley-Jones, D., & Stanley-Jones, K. (1960). *The kybernetics of natural systems. A study in patterns of control* (p. 60). London: Pergamon Press.
Swazey, J. P. (1969). *Reflexes and motor integration. Sherrington's concept of integrative action*. Cambridge, MA: Harvard University Press.
Tal Saban, M., & Kirby, A. (2018). Adulthood in developmental coordination disorder (DCD): A review of current literature based on ICF perspective. *Current Developmental Disorders Reports, 5*, 9-17.
Tal Saban, M., & Kirby, A. (2019). Empathy, social relationship and co-occurance in young adults with DCD. *Human Movement Science, 63,* 62-72.
Tallal, P., Miller, S., & Holly Fitch, R. (1993). Neurological basis of speech: A case for preeminence of temporal processing. In P. Tallal, A. M. Galaburda, R. R Llinás, & C. von Euler (Eds.), *Temporal information processing in the nervous system. Special reference to dyslexia and dysphasia* (pp. 27-47). New York, NY: Annals of the New York Academy of Sciences, *682*.
Teitelbaum, P. (1967). *Physiological psychology* (p. 67). Englewood Cliffs, N.J: Prentice-Hall, Inc.
The Séguin physiological school (1905/2017). *The Séguin physiological school for the training of children of arrested mental development.* Leopold Classic Library.
Thelen, E. (1979). Rythmical stereotypes in normal human infants. *Animal behaviour*, *27*, 699-715.
Thelen, E. (1998). Bernstein's legacy for motor development: How infants learn to reach. In M. L. Latash (Ed.), *Progress in motor control. Volume one, Bernstein's traditions in movement studies* (pp. 267-288). Champaign, IL: Human Kinetics.
Thelen, E., & Bates, E. (2003). Connection and dynamic systems: Are they really different? *Development Science 6,* 378-391.
Thelen, E., & Smith, L. B. (2006). Dynamic systems theories. In R. M. Lerner (Ed.), *Handbook of child psychology, volume 1. Theoretical models of human development* (pp. 258-312). Hoboken, NJ: John Wiley & Sons Inc.
Touwen, B. C. L. (1984). Primitive reflexes - conceptional or semantic problem? In H. F. R. Prechtl (Ed.), *Continuity of neural functions from prenatal to postnatal life* (pp. 115-125). Oxford: Spastics International Medical Publications.
Tupper, D. E., & Sondell, S. K. (2004). Motor disorders and neuropsychological development. A historical appreciation. In D. Dewey & D. E. Tupper (Eds.), *Developmental motor disorders. A neuropsychological perspective* (pp. 3-25). New York, NY: The Guilford Press.
Van Boxtel, M. P., Bosma, H., Jolles, J., & Vreeling, F. W. (2006). Prevalence of primitive reflexes and the relationship with cognitive change in healthy adults: A report from the Maastricht aging study. *Journal of Neurology*, *253*, 935-941.
Vanderplasschen, W., Rapp, R. C., Pearce, S., Vandevelde, S., & Broekaert, E. (2013). Editorial: Mental health, recovery, and the community. *Scientific World Journal*, *2013*:926174.
Von Bertalanffy, L. (1993). *General system theory*. *Foundations, development, applications.* New York, NY: George Braziller, Inc.
Wade, N. J. (2009). The search for a sixth sense. The cases for vestibular, muscle, and temperature senses. In D. Howes (Ed.), *The sixth sense reader* (pp. 55-86). Oxford: Berg.

Wann, J. (2007). Current approaches to intervention in children with developmental coordination disorder. *Developmental Medicine & Child Neurology*, *49*, 405.
Weiden, P., Aquila, R., & Standard, J. (1996). Atypical antipsychotic drugs and long term outcome in schizophrenia. *Journal of Clinical Psychiatry*, *57*, 53-60.
Wenzel, D. (1978). The development of the parachute reaction: A visuo-vestibular response. *Neuropadiatrie, 9*, 351-359.
Werner, H. (1957). The concept of development: An issue in the study of human behavior. In D. B. Harris (Ed.), *The concept of development from a comparative and organismic point of view* (pp. 125-148). Minneapolis, MI: University of Minnesota Press.
Whitehead, M. (2001). The concept of physical literacy. *European Journal of Physical Education 6*, 127-138.
Windle, W. F. (1971). *Physiology of the fetus. Relation to brain damage in the perinatal period* (p. 78). Springfield, IL: Charles C. Thomas Publisher.
Winnicott, D. W. (1954/2007). *Through paediatrics to psychoanalysis. Collected papers* (pp. 278-294). London: Karnac Books.
Wilson, P. H. (2005). Practitioner review: Approaches to assessment and treatment of children with DCD: An evaluative review. *Journal of Child Psychology and Psychiatry 46*, 806-823.
Yaniv, D. (2018). Trust the process: A new scientific outlook on psychodramatic spontaneity training. *Frontiers in Psychology*, *9*: 2083.
Zohar, D. (1991). *The quantum self* (pp. 107-122). London, UK: Flamingo.

APPENDIX

Paper I

Niklasson, M., Niklasson, I., & Norlander, T. (2009). Sensorimotor therapy: Using stereotypic movements and vestibular stimulation to increase sensorimotor proficiency of children with attentional and motor difficulties. *Perceptual and Motor Skills, 108,* 643-669.

Abstract

The current naturalistic study examined whether sensorimotor therapy utilizing the training program, Retraining for Balance, might be an appropriate technique for sensorimotor proficiency. The 232 children (181 boys, 51 girls), whose mean age was 9.3 yr. (SD = 2.7), presented attentional and motor difficulties (according to the School Health Care) as indicated by their parents before starting therapy. The children were divided into three groups, i.e., a younger group (7 yr. old or younger, n = 65), a middle group (8 to 10 yr. old, n = 91), and an older group (11 yr. old or older, n = 76). The program has seven parts, including fetal and neonatal movements, vestibular and auditory perceptual stimulation, and gross motor movements, among others. The treatment period was close to 3 yr. on the average. Analyses in a repeated-measures design indicated significant improvement of sensorimotor skills among the three age groups, but the older children performed better than the others on several tests. There were only a few sex differences. Retraining for Balance may be a functional technique for training children and youth with sensorimotor difficulties and might constitute a complement to regular treatment of Developmental Coordination Disorder, Learning Disability, and ADHD, but controlled studies are necessary before more decisive conclusions can be drawn.

Paper II

Niklasson, M., Niklasson, I., & Norlander, T. (2010). Sensorimotor therapy: Physical and Psychological regressions contribute to an improved kinesthetic and vestibular capacity in children and adolescents with motor difficulties and concentration problems. *Social Behavior and Personality, 38,* 327-346.

Abstract
Our aim was to gain increased understanding of the effects of sensorimotor therapy on the physical and psychological development of children and young people when using the method Retraining for Balance. The records of 8 children who had completed the program were randomly selected from a cohort of 232 with sensorimotor difficulties and concentration problems. The participants, 7 boys and 1 girl, averaged 9 years of age. The Empirical Phenomenological Psychological method (the EPP-method, Gunnar Karlsson, 1995) was used for this analysis, which resulted in 29 categories which yielded 3 overarching themes: a) the introduction of sensorimotor exercises, b) regression to earlier sensorimotor and psychological behaviors, and c) transformations in which the sensorimotor and psychological skills of the children matured and developed. The themes formed the kinesthetic-vestibular developmental model illustrating how sensorimotor exercises push the therapy process forward while recurrent regressions are followed by positive developmental phases. The results of the study were generalized to the remaining 224 children in the cohort by comparing each individual's records to the kinesthetic-vestibular model.

Paper III

Niklasson M., Rasmussen P., Niklasson I., & Norlander T. (2015). Adults with sensorimotor disorders: Enhanced physiological and psychological development following specific sensorimotor training. *Frontiers in Psychology, 6:* 480.

Abstract
The aim of the study was to investigate, for the first time, if it is possible to integrate primary reflexes in adults with sensorimotor disorders through sensorimotor therapy (SMT). Participants consisted of 14 adults, one man and 13 women, with an average age of 35 years who completed a SMT program over 3 years. They were compared with a reference group of 100 youngsters spanning from 11 to 17 years. Procedures were the same for both youngsters and adults including regular visits to a therapist and training ~15 min each day at home throughout therapy. Assessments of sensorimotor abilities were made before and after the therapy. Results showed significant improvements on all measurements with regard to treatment for both age groups and the main picture indicated small differences between age groups. After therapy adults were better on balance and orientation tests while the youngsters performed better on sports related gross motor movements, processing of speech sounds and had acquired a better relation between visual skills and vestibular function. Conclusions were that motor problems do not disappear with age and that the same diagnostic instruments and treatment methods can be used for both children and adults with sensorimotor difficulties.

Paper IV

Niklasson M., Norlander T., Niklasson I., & Rasmussen P. (2017). Catching-up: Children with developmental coordination disorder compared to healthy children before and after sensorimotor therapy. *PLoS ONE, 12,* (10):e0186126.

Abstract
The aims of the present study were to (a) compare healthy children in terms of sensorimotor maturity to untreated children diagnosed with developmental coordination disorder (DCD) and (b) compare healthy children to diagnosed children following completed treatment with sensorimotor therapy. Participants were 298 children, 196 boys and 102 girls, distributed into a Norm group of healthy children (n = 99) and a group of children diagnosed with DCD (n = 199) with a total mean age of 8.77 years (SD = 2.88). Participants in both groups were assessed on instruments aimed to detect sensorimotor deviations. The children in the DCD group completed, during on average 36 months, sensorimotor therapy which comprised stereotypical fetal- and infant movements, vestibular stimulation, tactile stimulation, auditory stimulation, complementary play exercises, gross motor milestones, and sports-related gross motor skills. At the final visit a full assessment was once more performed. Results showed that the Norm group performed better on all sensorimotor tests as compared to the untreated children from the DCD group, with the exception of an audiometric test where both groups performed at the same level. Girls performed better on tests assessing proprioceptive and balance abilities. Results also showed, after controls for natural maturing effects, that the children from the DCD group after sensorimotor therapy did catch up with the healthy children. The concept of "catching-up" is used within developmental medicine but has not earlier been documented with regard to children and youth in connection with DCD.

Paper V

Niklasson M., Rasmussen P., Niklasson I., & Norlander T. (2018). Developmental coordination disorder: The importance of grounded assessments and interventions. *Frontiers in Psychology, 9:* 2409.

Abstract
This focused review is based on earlier studies which have shown that both children and adults diagnosed as having developmental coordination disorder (DCD), benefited from sensorimotor therapy according to the method Retraining for Balance (RB). Different approaches and assessments for children and adults in regard to DCD are scrutinized and discussed in comparison to RB which mainly includes (a) vestibular assessment and stimulation (b) assessment and integration of aberrant primary reflexes and (c) assessment and stimulation of auditory and visual perception. Earlier results indicate that the process of Sensorimotor therapy using RB techniques could be described according to a conceptual Kinesthetic-Vestibular Developmental Model (KVDM) whereby the training elicited temporary physical and psychological regressions followed by transformations i.e., positive physical and psychological development. We have also seen that this recurring pattern is similar for children and adults. In our conceptual model vestibular stimulation (perceptual priming) stimulates the nervous system, which might enhance object-related priming. This perceptual priming will also assist the suppression of persistent aberrant primary reflexes. In order to develop effective methods for assessment and intervention of DCD over the life span the importance of primary reflex inhibition and vestibular stimulation as well as a combination of bottom-up and top-down approaches have to be considered.