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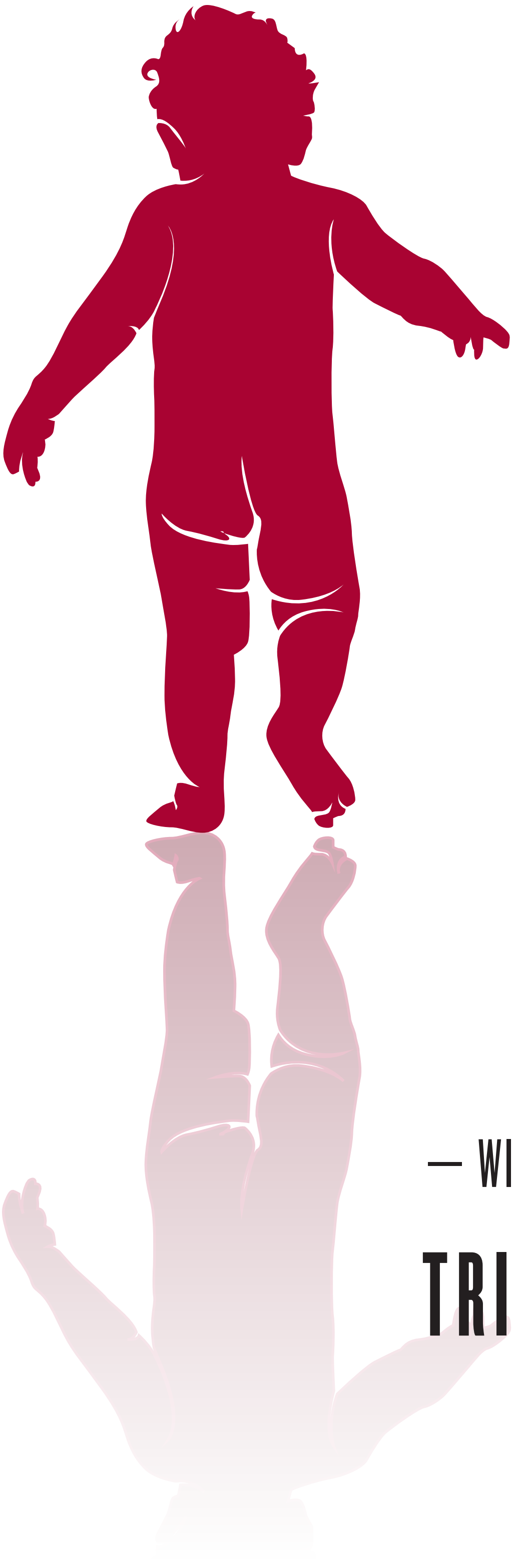

EARLY PREDICTORS OF INTELLIGENCE AND PERSONALITY

– WITH A FOCUS ON DEVELOPMENTAL MILESTONES

TRINE FLENSBORG-MADSEN

DOCTORAL DISSERTATION

The Faculty of Health and Medical Sciences at the University of Copenhagen has accepted this dissertation for public defence for the doctoral degree in medicine.

Copenhagen, 6 June 2021

Ulla Wewer, Head of Faculty

The public defence will take place 29 October 2021 at 1.00 p.m. in Auditorium 1, Gothersgade 140, Copenhagen.

A special thanks to the assessment committee:
Professor Katri Raikkonen, University of Helsinki
Professor Tine Brink Henriksen, Aarhus University
Professor Gorm Greisen, University of Copenhagen, chair

Thanks also to the leader of the public defence:
Professor Lisbeth E. Knudsen, University of Copenhagen

Early Predictors of Intelligence and Personality

–with a focus on developmental milestones

Trine Flensborg-Madsen

Copenhagen, 2021

'*He who thus considers things in their first growth and origin, whether a state or anything else, will obtain the clearest view of them*.' (Aristotle, 350 BCE)[1]

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Preface

My interest in the developing child began when I enrolled at medical school with a clear purpose of becoming a paediatrician. However, acknowledging my large interest in research, I decided to shift career and took my candidate degree in public health—and later also in psychology.

My research in children's development did not begin until after my PhD when I became aware of the incredible data that was available from the Copenhagen Perinatal Cohort and when my collaboration with Erik Lykke Mortensen accelerated. I was employed as an Assistant Professor and later as an Associate Professor at the Unit of Medical Psychology, Department of Public Health, when my research was directed towards the psychological outcomes of early development. The planning of this dissertation was thus conducted during my first year at the unit in 2013—without any publications on the subject at that point, but with a clear vision of the endpoint, even the title of the dissertation which has not changed.

I owe thanks to several people, but first and foremost, a very special person, Erik Lykke Mortensen. Besides being the optimal research companion and the co-author of all 12 papers included in this dissertation, he is my role model and has been my mentor for more than 10 years. I would not have been where I am today without his support and guidance, and I am forever thankful for our collaboration and friendship.

I want to thank all my present and former colleagues at the Unit of Medical Psychology for a stimulating, caring, and fruitful environment that has provided me with optimal conditions to write this dissertation, an environment that I have been lucky enough to have been part of for the last seven years and have been the leader of. I am especially grateful to Cathrine Lawaetz Wimmelmann, Gunhild Tidemann Okholm, Marie Stjerne Grønkjær, and Rasmus Revsbech for taking time to comment on the dissertation. Furthermore, a special thanks goes to my co-authors on the included papers Erik Lykke Mortensen, Holger Jelling Sørensen, Rasmus Revsbech, Cathrine Lawaetz Wimmelmann, Marie Stjerne Grønkjær, and Hanne-Lise Falgreen Eriksen.

Several people have inspired me in my early career, and although they were not directly involved in this dissertation, I want to thank Joav Merrick, who I have known since I was a student and who is still a good friend and sparring partner, and Leo Sher, who mentored me during my research stay at Columbia University and whom I have had close contact with since then.

Lastly, I would like to thank the Carlsberg Foundation for the Semper Arden monograph grant I received to write this dissertation. It has been a privilege to be able to spend the amount of time needed to finish this work.

I acknowledge the crucial role of Aage L. Villumsen and Bengt Zachau-Christiansen in the establishment of the Copenhagen Perinatal Cohort and June Reinisch and colleagues for establishment of the PDP database. Furthermore, I thank the staff at the Department of Public Health and the National Research Centre for the Working Environment, who undertook the CAMB data collection, and to those who initiated and established the cohort. Additionally, I am indebted to all participants for taking part in the studies.

Finally, and mostly out of love, thanks to Rasmus for support and never-ending patience, and to our three boys—Asger, Holger, and Folke—for real-life perspectives on milestone development and for making sure that I also know a whole lot about other equally important issues related to, for example, forms, sizes, and

skills of all kinds of superheroes. Even amazing superheroes like you have different trajectories with regard to milestones, personalities, and life, which is a crucial aspect to remember as a parent as well as a researcher.

Trine Flensborg-Madsen

Copenhagen, September 2021

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List of papers

I. Flensborg-Madsen T, Sørensen HJ, Revsbech R, Mortensen EL. Early motor developmental milestones and level of neuroticism in young adulthood: a 23-year follow-up study of the Copenhagen Perinatal Cohort. Psychological Medicine 2013;43:1293-1301.

II. Flensborg-Madsen T, Revsbech R, Sørensen HJ, Mortensen EL. An association of adult personality with prenatal and early postnatal growth: the EPQ lie-scale. BMC Psychology 2014;2(1):8.

III. Flensborg-Madsen T & Mortensen EL. Infant SES as a predictor of personality—Is the association mediated by intelligence? PLoS ONE 2014;9(7):e103846.

IV. Flensborg-Madsen T & Mortensen EL. Infant developmental milestones and adult intelligence: A 34-year follow-up. Early Human Development 2015;91:393-400.

V. Flensborg-Madsen T & Mortensen EL. Predictors of motor developmental milestones during the first year of life. European Journal of Pediatrics 2016;176:109-119.

VI. Flensborg-Madsen T & Mortensen EL. Birth weight and intelligence in young adulthood and midlife. Pediatrics 2017;139(6):e20163161.

VII. Flensborg-Madsen T & Mortensen EL. Associations of early developmental milestones with adult intelligence. Child Development 2018;89:638-648.

VIII. Flensborg-Madsen T & Mortensen EL. Developmental milestones during the first three years as precursors of adult intelligence. Developmental Psychology 2018;54:1434-1444.

IX. Flensborg-Madsen T & Mortensen EL. Language development and intelligence in midlife. British Journal of Developmental Psychology 2018;37:269-283.

X. Flensborg-Madsen T, Grønkjær M, Mortensen EL. Predictors of early life milestones: Results from the Copenhagen Perinatal Cohort. BMC Pediatrics 2019;19:420.

XI. Flensborg-Madsen T, Wimmelmann CL, Mortensen EL. A potential link between early language developmental milestones and personality traits in adulthood. International Journal of Behavioral Development 2020;44:383-392.

XII. Flensborg-Madsen T, Eriksen H-LF, Mortensen EL. Early life predictors of intelligence in young adulthood and middle age. PLoS ONE 2020;15(1):e0228144.

I. Summary

Background

Intelligence and personality are considered core mental characteristics in human development and are associated with a range of different life outcomes, including health aspects. It is, however, not clear how individual differences in intelligence and personality arise, how they develop, and the extent to which they can be traced back to early-life development.

The dissertation contributes to the literature on early predictors of intelligence and personality by empirically testing the relationship between a range of possible predictors in relation to intelligence and personality, with a particular focus on the timing of developmental milestones in the first years of life.

Objectives

The dissertation aims to provide a comprehensive picture of early-life factors that are associated with intelligence and personality in adulthood. Specifically, it aims at addressing the relationship between various measures of intelligence and personality assessed at different ages in adulthood, and the following early-life factors: timing of 1-year milestones, timing of 3-year milestones, birth weight, size in the first years of life, and parental socio-economic status.

Material

The dissertation is based on empirical findings on early predictors of intelligence and personality from 12 epidemiological studies. These studies are based on data from the Copenhagen Perinatal Cohort, including two follow-up studies of this cohort: the Prenatal Development Project and the Copenhagen Aging and Midlife Biobank. Additionally, data from the military draft board examination were included.

Results

The combined evidence of this dissertation suggests that several early-life factors are associated with IQ in adulthood. A study investigating the contributions of a broad selection of potential predictors found that parental socio-economic status and sex were the main predictors of IQ, while other consistent predictors were mainly related to physical size (especially head circumference) and behavioural characteristics (milestone development). Additional main findings of the included studies show that faster attainment of infant motor developmental milestones was associated with increased IQ in adulthood. Furthermore, faster attainment of milestones in the subsequent years, namely milestones related to language and social interaction, were associated with increased IQ in adulthood. Birth weight, and especially birth weight adjusted for gestational age, was associated with IQ at three different adult ages with IQ scores increasing across the four lowest birth weight categories up to 4 kg and declining for the highest category (>4 kg).

Several early-life factors were also associated with personality in adulthood. The main findings of the included studies were that faster attainment of infant developmental milestones and language milestones was associated with decreased neuroticism in adulthood. Additionally, faster attainment of language was associated with increased extraversion and openness to experience in midlife. In men, smaller size at birth and the following three years were associated with higher adult scores on the lie-scale of Eysenck's

Personality Questionnaire but not with other personality traits. Higher parental socio-economic status at the age of one year was associated with lower neuroticism, higher psychoticism, and lower lie-scale score; however, these associations seemed to be mediated by intelligence.

The findings of the dissertation are generally supported by the literature. However, the dissertation adds to the existing knowledge as the studies are based on outcomes of intelligence and personality in adulthood, include detailed, comprehensive measures of milestone development and are based on a birth cohort that is not characterised by delayed or atypical development.

Finally, the dissertation provides two comprehensive overviews of predictors of 1- and 3-year milestones, respectively. The main findings were that, among the included predictors, individual differences in the timing of 1-year milestones could mainly be explained by gestational age and birth weight while individual differences in the timing of 3-year milestones could mainly be explained by development in the first year.

Conclusions

The dissertation demonstrates lifelong connections between factors in the first years of life and individual differences in intelligence and personality in adulthood, underlining a stability of development from early to late life. It contributes to the existing research by pointing out specific factors that may be especially important for the development of intelligence and personality.

Whether these associations are caused by direct effects of early-life factors, by reverse causation of the effects of early intelligence and personality on early-life development, by mutual associations, or by confounding factors cannot be determined from these studies. However, a solid understanding of the mechanisms behind the findings is needed before information on early-life predictors of intelligence and personality can be used to design prevention and intervention programs. While the demonstrated associations are unlikely to have substantial consequences at the individual level, they may have important societal and public health implications.

II. Introduction

Intelligence and personality are today considered core mental characteristics in human development over the life course. Thus, research has consistently documented high intelligence and core personality traits to be associated with subjective well-being, educational and occupational success, life events, psychopathology, morbidity, and mortality.[2-13] It is, however, still not clear how these individual differences arise, how they develop, and to what degree they can be traced back to early-life development.

A growing body of knowledge exists on the importance of early-life environment for health later in life. The 'Barker's hypothesis' emerged more than 30 years ago from epidemiological studies of infant mortality, revealing high geographic correlations between rates of infant mortality and rates of adult death, especially from ischemic heart disease. These observations led to theories of under-nutrition during gestation as an important early origin of adult cardiac and metabolic diseases[14-16] and initiated worldwide interest in the idea of developmental plasticity,[17] which led to the developmental origins of health and disease (DOHaD) hypothesis.[18-20] Since then, studies have expanded beyond cardiovascular conditions[21,22] into a wide range of outcomes, including diabetes,[22,23] respiratory diseases,[24,25] cancer,[26,27] and psychiatric outcomes.[28]

The DOHaD hypothesis suggests that favourable (or unfavourable) fetal conditions have life-long health consequences for adult health outcomes. An underlying assumption within the DOHaD field is that specific factors (including nutritional, hormonal, and metabolic factors) that are active during sensitive and critical periods of development may permanently affect the health of the growing fetus, by affecting the structure and physiology of cells and organs.

The brain-sparring effect has been suggested to result in the growth of the brain at the expense of other organs, but effects of the early environment have also been found for brain development.[29] If a suboptimal early-life environment has consequences for subsequent health and morbidity through processes changing the physical structure of the human body, including the brain, an important question is whether it may also influence individual differences in the development of cognition and personality traits. This has inspired the author of the current dissertation to conduct a series of studies to investigate the issue.

Experiences in infancy and the first years of life are assumed to establish habits of noticing, obtaining, interpreting, and incorporating new and more complex experiences as well as to establish schemas for categorising and thinking about experiences. Thus, in addition to fetal conditions, the first years of life may be considered crucial to the development of mental characteristics. However, early-life predictors of intelligence and personality are still debated and far from elucidated.

This doctoral dissertation contributes to the research area on predictors of intelligence and personality by empirically testing the relationships of these mental characteristics with a range of possible early predictors. It is built on studies that investigate not only fetal conditions, as suggested by the original DOHaD hypothesis, but also on studies investigating predictors in the first years after birth. Thus, new evidence has been provided on how specific factors during the first years of life may contribute to individual differences in intelligence and personality.

Objectives

This dissertation aims to provide an overview of early predictors of intelligence and personality with a particular focus on developmental milestone attainment.

Specifically, the dissertation aims to give an overview of early predictors of intelligence and also to address the relationships of intelligence with 1-year milestones, 3-year milestones, and birth weight. Furthermore, it aims to address the relationship of adult personality with 1-year milestones, 3-year milestones, size at birth and the subsequent years, and parental socio-economic status. Finally, the dissertation aims to provide an overview of predictors of milestone development in the first year of life as well as predictors of milestone development in the subsequent years.

The dissertation is based on results from the Copenhagen Perinatal Cohort (CPC), including two adult follow-up studies of this birth cohort: the Prenatal Development Project (PDP) and the Copenhagen Aging and Midlife Biobank (CAMB). Additionally, data from the military draft board (MDB) examination served as a third adult follow-up.

Outline

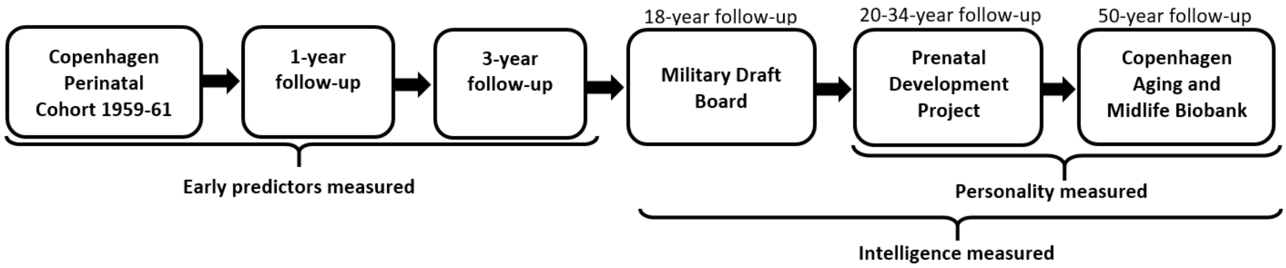
The dissertation consists of 12 original papers and a scientific summary. None of the 12 papers has previously been included in work evaluated for the purpose of achieving an academic degree.

The scientific summary is structured around 10 chapters, with the rationale and objectives presented in the current Chapter II. Chapter III is a brief introduction to the CPC, and the follow-up studies of this cohort. Chapter IV presents a short theoretical introduction to the concepts of intelligence and personality, including clarifications of the conceptualisations and descriptions of the relevant assessment instruments, while Chapter V describes the early predictors that are being investigated. The following three chapters (Chapters VI, VII, and VIII) focus on presenting the empirical results of the papers included in the dissertation and discuss the findings in relation to the existing literature. The three chapters cover intelligence, personality, and milestones, respectively. Each chapter includes discussions of potential underlying mechanisms and selected methodological issues. Final conclusions of the evidence of early predictors of intelligence and personality are summarised in Chapter IX. The conclusion is briefly put into a public health perspective in the final Chapter X, which also discusses new directions for future research.

III. The Copenhagen Perinatal Cohort and follow-up studies: An overview.

The papers included in the dissertation are all based on the Copenhagen Perinatal Cohort (CPC) and several follow-up studies of this cohort, as illustrated in Figure 1. Thus, information on various early predictors was obtained from the CPC in addition to 1-, 3- and 6-year follow-ups, while information on adult intelligence was obtained from the military draft board (MDB) in addition to two follow-ups of the CPC: The Prenatal Development Project (PDP) and The Copenhagen Aging and Midlife Biobank (CAMB). Personality test scores were obtained from PDP and CAMB.

Figure 1. Overview of the study design



The Copenhagen Perinatal Cohort

Between September 1959 and December 1961, the CPC was established with data on 8949 mothers and their 9125 children born at Rigshospitalet.[30] Information on demographic, socio-economic, family background, and prenatal factors in addition to information on delivery and postnatal examinations were recorded prospectively during pregnancy and at delivery.[31] At the time of investigation, the following medical indications gave access to delivery at Rigshospitalet: complications of pregnancy, anticipated complicated delivery, previously complicated pregnancies or deliveries, and the mother being ≥35 years of age, together with social indications including single mothers or mothers in poor social conditions (essentially poor housing condition).[30] The mothers were mainly residents of Copenhagen or the nearest districts.

The cohort is thus selected and characterised by a higher frequency of complications, including abortions, and a higher incidence of single mothers than in the general population. A factor that especially separates this cohort from younger birth cohorts is the prevalence of smoking during pregnancy, which was around 50 per cent.

1-, 3-, and 6-year follow-ups

Follow-up examinations were carried out when the children were approximately 1, 3, and 6 years of age. At all examinations, anthropometric measurements were obtained of the child, and the mother was interviewed about the child's development. At the 1-year examination, a standardised diary was returned by the mother. The diary included information on the timing of 12 developmental milestones. The mother had been instructed to use this diary during the child's first year of life, and in cases where the mother did not return the diary, an effort was made to obtain retrospective information.[32] At the 3-year examination, the mothers were interviewed and asked to recall the ages at which the child first reached 20 developmental milestones.

Data from the 1-year follow-up were included in all papers because 1-year parental socio-economic status (SES) was used in all studies. The 3-year follow-up was included in *Papers II, VII, VIII, IX, X, XI*, *and XII*, and the 6-year follow-up was used in *Paper II*.

Military draft board

The earliest adult follow-up used in the dissertation is the MDB from which information on intelligence was available by Børge Priens Prøve (BPP). As all Danish men are obliged to appear before the draft board unless they suffer from special conditions (e.g., diabetes, epilepsy, or intellectual disability) or have volunteered for military service at an earlier age,[33,34] this follow-up is considered to comprise the most unselected sample of the three adult follow-ups; however, it includes only men. A total of 3307 men from the CPC had information on BPP. At the time of testing, the age range of participants was 16–24 years. The MDB was utilised in *Papers VI, VIII, and XII.*

Prenatal Development Project

Between 1982 and 1994, 1575 individuals from the CPC were invited to participate in PDP.[35,36] Index individuals were selected to participate based on prenatal exposure to steroid hormones and barbiturates and matched to at least one unexposed member of the CPC. Thus, an overweight of individuals exposed to prenatal medication (45%) is present in this sample. A total of 1155 (73%) participants completed the Danish version of the original Wechsler Adult Intelligence Scale (WAIS), and 1182 (75%) completed the Eysenck Personality Questionnaire (EPQ). At the time of participation, the participant age range was 20-34 years. The PDP was utilised in *Papers I–IV, VI–VIII, XI*, *and XII.*

Copenhagen Aging and Midlife Biobank

Between 2009 to 2011, 5282 individuals from the CPC were invited to participate in CAMB, which is a follow-up study of the three cohorts: The CPC,[31] The Metropolit 1953 Danish Male Birth Cohort,[37] and the Danish Longitudinal Study on Work, Unemployment and Health.[38] However, only data from the CPC were used. A total of 1698 (32%) individuals from the CPC completed the Intelligenz-Struktur-Test 2000 R (I-S-T 2000R), and 1705 (32%) completed the NEO Five-Factor Inventory (NEO-FFI); both tests were administered as part of the clinical examinations at CAMB.[39,40] At the time of participation, the participant age range was 48–51 years. CAMB was utilised in *Papers VI, IX, XI and XII.*

Characteristics of the follow-up samples

Table 1 illustrates the characteristics of each follow-up study in terms of parental SES, sex distribution, and age at follow-up. Among the adult follow-ups, the MDB is the most general sample with regard to parental SES with a mean of 4 (scale from 1–8), while the other samples are characterised by a relative overweight of individuals with high parental SES. The gender distribution is close to equal between men and women in PDP while women are overrepresented in CAMB.

Table 1. Characteristics of CPC and each follow-up study (all available data utilised)

	CPC	1-year	3-year	MDB	PDP	CAMB
Parental SES, mean (SD)	-	4.0 (1.8)	4.5 (1.8)	4.0 (1.8)	4.7 (1.9)	4.4 (1.9)
Sex (% men)	51.2%	51.1%	52.0%	100%	50.6%	43.9%
Age, mean (SD)	-	1.1	3.1	19.2	27.6	50.1

Ethical considerations

Data collection for the CPC was part of regular hospital procedures, and all mothers giving birth between 21.9.1959 to 21.12.1961 were enrolled. According to the Danish regulations at the time when PDP was established, PDP was registered at the local scientific, ethical committee (No: V.200.1526/89), and the local scientific ethical committee approved the CAMB as a database combining three cohorts (No: H-A-2008-126). PDP and CAMB are both registered at the Danish Data Protection Agency (No: 2013-41-2593 and No: 2008-41-2938 respectively).

Participants in the PDP were reimbursed for expenses related to their participation in addition to 150 DKR. CAMB participants were reimbursed for transportation expenses. CAMB participants were also informed on relevant important findings from the research project after the examination day unless they had requested not to receive such information. Both PDP and CAMB participants signed informed consent forms and were free to withdraw from the study at any time.

IV. Intelligence and personality: Definitions and measures

In psychological testing, a score on a test is believed to reflect a psychological construct, and the implicit assumption is that a test measures individual differences in this construct. Operationalisations of the same construct are often multifarious and can be classified according to several characteristics; this is briefly explicated below for intelligence and personality, followed by descriptions of the instruments used to operationalise them in the present dissertation.

Intelligence

Intelligence is one of the earliest researched topics in psychology, but despite a long history of debates and research, there is still not one standard theoretical definition of intelligence that is agreed upon. However, strong similarities exist between many of the definitions that often describe the ability to achieve goals in a broad range of environments and include features such as the ability to learn and adapt, or to understand.[41] The following statement from 1994, agreed upon by 52 researchers, defines the concept in the following way:

> Intelligence is a very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience. It is not merely book learning, a narrow academic skill, or test-taking smarts. Rather, it reflects a broader and deeper capability for comprehending our surroundings – 'catching on,' 'making sense' of things, or 'figuring out' what to do.[42]

The basis for the assumption of a general mental capacity is the empirical observation that results of different cognitive tests almost always show positive and relatively high intercorrelations.[6] In other words, people who do well on one cognitive test also tend to do so on other cognitive tests, while people who do poorly also do so throughout. On this basis, Charles Spearman was the first to suggest that there is a general mental capacity or intelligence factor (also called the g factor) that to a varying degree plays a role in all cognitive tests (which is also influenced by an individual's talent for a specific test).[43] Others, including Thurstone,[44] have maintained that intelligence is more complex than a single g factor and suggested several primary abilities. However, empirical evidence suggests that the g factor accounts for 40 to 50 per cent of the between-individual differences on intelligence tests[45,46] and the g factor is the theoretical basis for summarising a person's performance by a single number, the intelligence quotient (IQ), which is derived from the sum of scores obtained on the included subtests. Comprehensive IQ batteries are also designed to assess an individual's relative performance in more specific cognitive domains such as reasoning or verbal and spatial ability, but domain or ability scores also tend to show high intercorrelations.[47] A hierarchical pattern of the components of intelligence was described by Spearman[47,48] and has been replicated in a number of studies.[47-49] In this dissertation, composite IQ measures are used, presumably reflecting a general mental ability.

Historically, the scientific study of human intelligence has been closely linked to the development of practical useful tests of individual differences in intelligence. The first successful intelligence test was developed by Alfred Binet at the beginning of the 20th century. He used children's age as an independent criterion of intelligence, and the tests were used to assign a 'mental age' to a child. The concept of intelligence quotient (IQ) was derived by dividing the mental age by the child's chronological age. Binet's tests were further developed by Terman and became known as the Stanford-Binet test, which is now in its fifth edition.[6,50] IQ derived from mental age cannot be applied to adults, and today, deviation IQs are used for both children and adults. Deviation IQs were introduced by Wechsler[36] and typically measure how far an individual differs from the mean of 100 on a scale with a standard deviation of 15.

IQ tests can be classified according to several characteristics; one is the number of subtests included. Thus, while the original version of Wechsler Adult Intelligence Scale (WAIS)[51] includes 11 subtests, and IST-2000 R[5] includes nine, only four subtests are included in Børge Priens Prøve (BPP),[34] and a single type of test is included in Raven's Progressive Matrices.[52] Generally, IQ tests with more diverse subtests are considered better measures of the g factor[6] because they minimise the influence of specific abilities or talents. Another characteristic of IQ tests is the weighting of fluid intelligence (ability to solve novel reasoning problems) and crystallised intelligence (ability to use learned knowledge and experience). While Raven and BPP mainly focuses on problem-solving and thereby fluid intelligence, tests with several subtests usually include tests related to both types of intelligence. The distinction between verbal and nonverbal subtests often coincides with the distinction between crystallised and fluid intelligence. Finally, IQ tests can be classified according to form of administration, the most important distinction being between individually administered tests (e.g., WAIS[51] and Stanford-Binet[50]) and tests administered to groups of people (e.g., BPP, Raven's Progressive Matrices,[52] and IST-2000 R).

IQ scores based on comprehensive test batteries such as the WAIS often show reliability estimates in the high 90s and are thus among the most precise measurements in psychology.[36] The stability of IQ scores increases through childhood, and there is evidence of remarkable stability of IQ through most of the lifespan;[53,54] however, absolute test scores increase throughout childhood and starts to decline in old age.[6]

In this dissertation, 'intelligence' is used to describe concepts while 'IQ' is used to describe scores, although some would argue that IQ should be based only on a score calculated based on a national representative norming sample. In the dissertation, IQ was measured in adulthood at three different time points:

Børge Priens Prøve (BPP)

At the military draft board (MDB) examination, IQ was measured by BPP. The test was developed by the Danish psychologist Børge Prien and initially administered in the early 1950s by the Danish Military Psychological Service. The BPP is a group-administered intelligence test in a paper-and-pencil format, which consists of four subtests assessing logic (letter matrices, 19 items), verbal (verbal analogies, 24 items), numerical (number series, 17 items), and spatial (geometric figures, 18 items) abilities.[34] The subject has to complete as many items as possible within 45 minutes, and the correct answers in each of the four subtests are summed to a total score from 0 to 78.[34] The four subtests have remained unchanged since the introduction of the BPP in 1956 and until today where it is still used in a computerised version, but only the total BPP score (and not subtest scores) were recorded for the paper version.

The inter-correlations among the subtests in BPP lie within the range of 0.4 to 0.6,[55] while correlations between individual subtest-scores and the total BPP score have been found to be in the range of 0.74 to 0.86.[55] Factor analysis found the first principal component to explain 65 per cent[56] of the variance, suggesting a strong g component.[34] Additionally, BPP has been found to correlate strongly with the WAIS (r=0.82) in a smaller sample of men from the CPC and to correlate 0.57 with Raven's Advanced Progressive Matrices.[34]

Wechsler Adult Intelligence Scale (WAIS)

At the Prenatal Development Project (PDP),[36] IQ was measured by the original version of WAIS. The test was originally developed in 1955[51] and has since then been revised as WAIS-R and more recently as WAIS-III and WAIS-IV.[57,58] The WAIS generates three IQ scores: verbal IQ (six subtests), performance IQ (five subtests), and full-scale IQ (sum of the 11 subtests). The verbal subtests comprise information, comprehension, arithmetic, similarities, digit span, and vocabulary, while the performance subtests consist of digit symbols, picture completion, block design, picture arrangement, and object assembly[51] (later versions of WAIS, such as WAIS-IV,[58] include a modified and expanded number of subtests). In PDP, the WAIS was individually administered by three psychologists, and the IQ scores were derived from Danish test norms.[36]

The inter-correlations among the subtests have been found to be positive, ranging from 0.30 to 0.77, and correlations among similar subtests are higher than correlations between different subtests.[6] The WAIS and Wechsler's other tests of intelligence have remained among the most widely used individually administered IQ tests and have shown high correlations with other IQ tests and with educational outcomes in general.[6]

The Intelligenz-Struktur-Test (I-S-T 2000 R)

At the Copenhagen Aging and Midlife Biobank Study (CAMB), IQ was measured by the Intelligenz-Struktur-Test (I-S-T 2000 R)[59] (translated into Danish by Hogrefe Publishers). The I-S-T 2000 R is an intelligence test in a paper-and-pencil format administered as a group test, which consists of nine subtests and is a revised version of I-S-T 70.[59] In the CAMB study, the participants completed only the following three subtests: sentence completion, verbal analogies, and number series. Each of the three subtests consists of 20 items, and the subject has to complete as many items as possible within 6, 7, and 10 minutes, respectively. The number of correct answers is summed to a total score ranging from 0 to 60, but as one item in the sentence completion test had very low correlations with the total score on the remaining items in both the subtest and the full test score, this item was dropped from the analyses, resulting in a maximum possible total score of 59.[60] Based on the study sample, the raw scores were standardised in this dissertation to a mean of 100 and a standard deviation of 15. The I-S-T 2000 R has generally shown good psychometric quality.[61]

The three measures of intelligence

As described, the dissertation is based on three different intelligence tests assessed at mean ages of 19, 28 and 50 years, respectively. Pearson correlation coefficients between the three scales for members of the CPC are shown in Table 2.

Table 2. Correlations between BPP, WAIS, and I-S-T 2000 R for singletons of the CPC

	BPP	WAIS
BPP	(n=3202)	
WAIS	0.81*** (n=485)	(n=1126)
IST-2000 R	0.76*** (n=602)	0.79*** (n=314)

*** <0.001

The highest correlations were found between BPP and WAIS, which were both assessed in young adulthood. Nevertheless, correlations between BPP and I-S-T 2000 R were r=0.76, although there were more than 30 years between the two tests. Two of the three I-S-T 2000 R subtests are similar to the corresponding BPP subtests (verbal analogies and number series). Although the I-S-T 2000 R includes number series, it appears reasonable to characterise the test as predominantly a test of verbal reasoning.[62] The BPP has been characterised as essentially a measure of abstract verbal reasoning or fluid intelligence.[63] In contrast, the WAIS is a more comprehensive instrument, providing broader composite IQ measures reflecting both crystallised and fluid intelligence. From this perspective and considering the interval between testings, the WAIS correlations of 0.79 and 0.81 with the IST 2000 R and the BPP are remarkably high.

Personality

As it is the case with intelligence, there is also not one standard definition of personality that is agreed upon. One approach to studying personality is trait theory in which the focus is on the measurements of traits. McCrae & Costa define personality traits as: '*dimensions of individual differences in tendencies to show consistent patterns of thoughts, feelings, and actions*'.[64] Historically, there has been general agreement on this definition, but the number of essential personality traits in addition to the conceptualisation of traits has been an area of great debate, some of which may reflect differences between British and American research traditions. For many years, Eysenck represented the British tradition, which was empirically based and originally focused on only two broad personality traits: neuroticism and extraversion (and later also psychoticism). In contrast, Cattell represented the American tradition, which was based on the lexical approach and included 16 personality traits measured with Cattell's Sixteen Personality Factor Questionnaire. Associations between traits of the two traditions were illustrated by both Eysenck and Cattell,[65,66] and Digman summarised evidence of five broad personality traits[67] called 'the big five': neuroticism, extraversion, openness, agreeableness, and conscientiousness. Based on the five-factor-model, McCrae and Costa developed the Revised NEO Personality Inventory (NEO-PI-R)[68] that today is one of the leading instruments used to assess the five traits[69] and has shown to have temporal stability,[64,70,71] high internal consistency,[64] and to be generalisable across cultures.[72] The newest version is the NEO-PI-3.[73]

There is a growing consensus that the five-factor model applies to both children and adults;[74-77] however, traits may be less distinctive in early childhood than they are later,[78,79] and also, their stability increases with age.[70,78] Personality traits can be subdivided into facets, which are specific and unique parts of the broader traits, sometimes labelled lower-level traits. In this dissertation, 'personality' and 'personality traits' are used to describe theoretically latent dimensions of personality while 'personality scores' or 'personality trait scores' are used to describe test scores. An overview of facets associated with the traits in the NEO-PI-R five-factor model is illustrated in Table 3.

Table 3. Personality traits and related facets of the NEO-PI-R five-factor model of personality[68]

Neuroticism (N)	Anxiety, angry hostility, depression, self-consciousness, impulsiveness, vulnerability
Extraversion (E)	Warmth, gregariousness, assertiveness, activity, excitement-seeking, positive emotions
Openness (O)	Fantasy, aesthetics, feelings, actions, ideas, values
Agreeableness (A)	Trust, straightforwardness, altruism, compliance, modesty, tender-mindedness
Conscientiousness (C)	Competence, order, dutifulness, achievement striving, self-discipline, deliberation

Most personality theories and instruments that are used today overlap with traits or facets contained in the five-factor model. In the CPC, personality was measured at the PDP and CAMB follow-ups by two different personality questionnaires:

Eysenck Personality Questionnaire (EPQ)

In the PDP, personality was assessed using EPQ. This inventory developed by Eysenck assesses three broad personality traits (neuroticism, extraversion, and psychoticism).[80] Contrary to earlier personality inventories such as the Eysenck Personality Inventory (EPI),[81] the EPQ (which was later revised in the Eysenck Personality Questionnaire-Revised (EPQ-R)[82]) was the first version to include the psychoticism scale. The Danish version of the EPQ comprises 101 binary 'yes' or 'no' questions from which scores on neuroticism (23 questions), extraversion (21 questions), and psychoticism (25 questions) are derived. Additionally, the lie-scale comprises 21 questions (the rest of the questions are 'reserve' questions included in the Danish version). Especially the scales of neuroticism and extraversion have shown robust psychometric properties.[83,84]

It has been suggested that psychoticism is largely redundant with agreeableness and conscientiousness constructs of the five-factor model,[85,86] and alternative labels such as psychopathy or impulsive unsocialised sensation-seeking[87] have been suggested. Included in EPQ is also a lie-scale intended to measure participants' tendencies to 'fake good' when completing the questionnaire. However, according to some studies, this dimension is best characterised as social acquiescence or conformity, or as a lack of self-insight.[88-91]

NEO Five-Factor Inventory (NEO-FFI)

In the CAMB, NEO-FFI was administered to assess personality. While the NEO-PI-R is a 240-item questionnaire that captures six different facets of each of the five personality traits, the NEO-FFI was designed to assess the domains in a more economical way but does not provide facet-specific information.[92] The American NEO-FFI was constructed by picking out the 5 x 12 items with the highest correlation with the relevant total factor score, while the Danish NEO-FFI was constructed by selecting two items among each of the six facets characterising the five personality traits assessed by NEO PI-R.[93,67] It assesses the traits neuroticism, extraversion, openness, agreeableness, and conscientiousness and is based on 12 items for each trait. The 60 items are scored on a Likert scale ranging from 0 (strongly disagree) to 4 (strongly agree), resulting in a score for all traits of 0–48.[94] Factor score correlations between NEO-PI-R and NEO-FFI factor scores have been found to be in the range of 0.89 to 0.93,[95] and the psychometric properties have generally been considered good.[96-99]

Table 4. Personality traits in EPQ and NEO-FFI

Eysenck Personality Questionnaire (EPQ)	NEO Five-Factor Inventory (NEO-FFI)
Neuroticism	Neuroticism
Extraversion	Extraversion
Psychoticism	Openness
Lie-scale	Agreeableness
	Conscientiousness

EPQ and NEO-FFI

The traits included in both instruments are significantly correlated in the data used in the present dissertation. Thus, the Pearson correlation coefficient between EPQ neuroticism scores and NEO-FFI neuroticism scores was r=0.57 and between the corresponding extraversion scores r=0.58. These correlations do, however, reflect a retest interval of three decades, while Danish data with simultaneous administration of EPQ-R and NEO-PI-R suggest substantially higher correlations of 0.76 for both neuroticism and extraversion.[95]

For both the EPQ and NEO-FFI, the latent personality traits assessed with each instrument are assumed to be uncorrelated, but this is rarely the case for empirical personality scores. In data from the CPC, significant correlations were found in the EPQ between neuroticism and extraversion and between extraversion and psychoticism. For the NEO-FFI, several significant correlations were also found between the traits, as shown in Table 5.

Table 5. Correlations between EPQ and NEO-FFI personality traits for members of the CPC

	EPQ N	EPQ E	EPQ P	NEO-FFI N	NEO-FFI E	NEO-FFI O	NEO-FFI A
EPQ E	-0.35*** (1182)	-					
EPQ P	0.01 (1182)	0.09** (1182)					
NEO-FFI N	0.57*** (336)	-0.29*** (336)	-0.13* (336)				
NEO-FFI E	0.30*** (336)	0.58*** (336)	0.04 (336)	-0.44*** (1704)			
NEO-FFI O	0.003 (336)	0.24*** (336)	0.10 (336)	0.004 (1704)	0.36*** (1703)		
NEO-FFI A	0.05 (336)	-0.16** (336)	-0.27*** (336)	-0.05* (1705)	0.006 (1704)	0.01 (1704)	
NEO-FFI C	-0.27*** (336)	0.14* (336)	-0.02 (336)	-0.50*** (1705)	0.31*** (1704)	0.05* (1704)	0.07** (1705)

*<0.05, **<0.01,*** <0.001

V. Early predictors: definitions and measures

A number of early factors have been suggested in the scientific literature to be possible predictors of intelligence and personality. In this dissertation, a special focus was on developmental milestones, and also, *Papers II and VI* focused on prenatal and early postnatal growth while *Paper III* focused on parental SES. In the following sections, the background and definitions of these three areas of predictors are presented.

Developmental milestones

The concept of development can most readily be described as change. As the infant and child grow, changes in many characteristics are prominent and observable,[100] and important achievements in skills and abilities define developmental milestones. Age of attaining developmental milestones can thus be understood as indicators of the speed of development. The developmental changes that take place during the first years of life are more dramatic than any others in the human lifespan and include the shape and capacity of the body, the complexity of the nervous system, sensory and perceptual capacities, and achievement of communication.[100] The milestones that are being investigated in the present dissertation are divided into two categories: milestones in the first year of life (1-year milestones) and milestones in the two subsequent years (3-year milestones).

1-year milestones

When babies are born, they have very little control over their bodies, and motor development is the process of learning how to establish this control and coordinate the muscles. Innate reflexes are regulated by lower levels of the brain, but they are eventually subordinated to more complex intentional movements that are conscious and monitored by higher levels of the brain. The process of developing motor skills is to a large extent dependent on the maturation of the central nervous system and the muscular system, and the infant's abilities to move progress with the development of these systems. Arnold Gesell was one of the first to study developmental milestones and presented norms for behaviour at successive stages of development.[101] He concluded, however, that development does not follow a straight line but instead progresses through faster and slower periods of maturation of the nervous system.

Motor development occurs in an expected sequence of actions for most children, and 'windows of attainment' have been suggested to provide standard age ranges for the attainment of motor milestones,[102,103] although there are individual differences in the age at which each skill is attained. Motor milestones are often divided into gross—and fine motor development, which together allow an infant to proceed from being entirely dependent to being a mobile and independent child who can move around in the environment and manipulate and use objects.

The emergence and continued development of new motor abilities during the first year, therefore, have consequences for the opportunities to understand properties of the environment,[104] and each transition reflects not only new ways for infants to interact with their environments but also new ways to gather information and interrelate with others.[105] Motor development has thus been found to provide opportunities for the development of a range of perceptual, social, and cognitive skills,[106] which makes it likely that it is also related to such skills later in life.

An overview of the 12 motor developmental milestones included in this dissertation is shown in Table 6, together with milestone means. The means were derived by constructing a dataset based on an EM algorithm[107] in which missing milestone data was replaced by imputed data. This dataset was utilised to conduct a principal component analysis of all 12 milestones, and both varimax and promax rotation defined three factors: (I) The smiling and lifting head factor comprised milestones 1–3; (II) the rolling, crawling, sitting, and grabbing factor, milestones 4–8; and (III) the standing and walking factor, milestones 9–12.[108]

Table 6. Overview of milestones from the 1-year examination

Milestone means:	Milestones	Description:
SMILING AND LIFTING HEAD	1. Lifts head on stomach (weeks)	The child can lift the head when placed on the stomach
	2. Smiles (weeks)	The child can smile
	3. Holds head when sitting	The child holds the head when pulling arms to a sitting position
ROLLING, CRAWLING, SITTING AND GRABBING	4. Grasps after things	The child grasps after things and holds on to them
	5. Rolls	The child rolls from back to stomach
	6. Sits without support	The child can sit without support
	7. Crawls	The child can crawl
	8. Crawls longer distance	The child can crawl a longer distance (e.g., across the living room)
STANDING AND WALKING	9. Stands with support	The child can stand when supported
	10. Stands without support	The child can stand unsupported
	11. Walks with support	The child can walk when supported
	12. Walks without support	The child can walk unsupported

3-year milestones

In the following years, from age one to age three, milestones attained by the child become more and more multifaceted and include language in addition to more complex forms of gross and fine motor development and more advanced forms of social interaction. The majority of these skills develop based on milestones obtained in the first year. For example, the ability to be able to sit and stand enables fine motor development such as eating with a spoon and communicating with others, while walking enables social interaction in general. A special focus in the dissertation is on language development, as milestones related to language were found to be those that were most strongly associated with intelligence and personality.[109,110]

Typically, children develop receptive language first, which is the internal processing and understanding of language, and as it continues to increase, expressive language begins to develop. Learning language is considered to be essentially tied to the internationalisation of cultural values and norms that are integral in the language.[111] Several theories have evolved on the associations between language and thought;[111-115] some suggesting that language directly affects the thinking process. Thus, Vygotsky believed that communication plays a central role in the process of 'making meaning',[116] and the Sapir-Whorf hypothesis[117] also suggests a causal relationship between language and thought. However, the causality of language and thought has been greatly discussed.[118] Since language plays a central part in most human social interaction, it is also plausible that development of language contributes to both the internal processing of social interaction in addition to the different reactions from others to this interaction, which is likely to affect the subsequent development of the child.

Information on 20 milestones typically attained in the second and third years of life was retrospectively obtained at the 3-year examination of the CPC. Table 7 presents an overview of these, together with the milestone means. The means were, as the 1-year means, derived by conducting a principal component analysis of all 20 milestones in a dataset with missing values imputed based on an EM algorithm[107] and both varimax and promax rotation defined six factors.

Table 7. Overview of milestones from the 3-year examination

Milestone Means	Milestones	Description
LANGUAGE	1. Turning head in the right direction	The child can turn head in the right "direction" if you, e.g., say: where is. 'mom', 'dad', 'the light' etc.
	2. Naming objects/animals	The child can name a few, familiar objects or animals with their true names
	3. Naming objects/animals in pictures	The child can name a few, familiar objects or animals in pictures with their true names
	4. Forming a sentence	The child can put at least three words together to form a 'sentence'
	5. Speaking properly	The child can speak properly
	6. Sharing experiences	The child can talk about what it has experienced
WALKING	7. Walking	The child can walk around unassisted in the living room
	8. Climbing stairs	The child can climb stairs unassisted
EATING	9. Drinking from cup	The child can drink from a cup without assistance
	10. Eating with spoon	The child can eat with a spoon without assistance
DRESSING	11. Putting on socks	The child can put socks on by itself
	12. Doing buttons	The child can do buttons
SOCIAL INTERACTION	13. Building tower	The child can build a tower of 4-5 ordinary rectangular blocks
	14. Helping at home	The child shows interest in helping at home by imitating parents (e.g., by laying the table or other domestic tasks)
	15. Picking up things	The child can pick up things in the apartment if requested
	16. Playing with peers	The child plays with children of the same age (e.g., rolling a ball to each other)
	17. Distinguishing boys and girls	The child can distinguish between boys and girls
TOILET TRAINING	18. Bowel control	The child can tell when it needs to defecate
	19. Dry during the day	The child is dry during the day and tells when it needs to go to the toilet
	20. Dry during the night	The child is dry during the night

Pre- and postnatal growth

Birth weight is consistently used as an indicator of neonatal health in order to provide an overall measure of fetal nutrition and other in utero exposures; this is perhaps because birth weight is often available in datasets. Birth weight is typically categorised for the purpose of research and policymaking to identify infants who fall into high- or low-risk groups. Low birth weight is defined by the World Health Organization (WHO) as less than 2500g at delivery[119] and is often subdivided into very low birth weight (less than 1500g) and extremely low birth weight (less than 1000g). A general consensus on a category for high birth weight does not exist but is often defined as more than 4000g.[120]

The birth weight of an infant is generally dependent upon both the duration of pregnancy and the rate and extent of fetal growth, and factors of importance to these concern both the infant, the mother, and the physical environment. For the same gestational age, it has been found that, in general, girls weigh less than boys, firstborns are lighter than subsequent siblings, and twins weigh less than singletons.[119] Additionally, birth weight is affected by the mother's own fetal growth and her diet from birth to pregnancy—and thus her body composition; hence younger and shorter women generally give birth to infants with lower birth weights. After the women is pregnant, the nutrition and diet, lifestyle, and diseases can also affect fetal growth, and mothers from deprived socio-economic environments frequently have infants with lower birth weights.[119]

Due to these adverse risk factors, infants in a specific birth weight category defines a heterogeneous group with many potential causes. However, conclusions of the DOHaD hypothesis,[18-20] suggesting that fetal conditions have life-long health consequences for adult outcomes[121-124] have often been drawn based on studies of birth weight as a proxy of favourable fetal conditions. The use of a single observed measure as a proxy variable has been criticised, and it has been suggested that other measures at birth, such as length, head circumference, or the Apgar score are more informative measures.[125,126] Moreover, the long-term health outcomes for large babies have changed in the past 30 years, possibly due to nutritional excess in utero,[120] and a large increase in the frequency of large babies has also been found in recent decades.[120]

As with birth weight, weight increase in the first years of life has also been an area of interest, and child growth charts are among the most commonly used tools for assessing the health of individual infants and children in addition to the general health of the community.[127,128]

In this dissertation, birth weight was investigated as a predictor of IQ (*Paper VI*), while weight, length, and head circumference at birth and the following six years were investigated as predictors of personality trait scores (*Paper II*). Additionally, measures of weight, length, and head circumference were investigated in the three overview studies of predictors of IQ (*Paper XII)* and milestones (*Papers V and X).* Finally, birth weight was included as a potential confounding factor in all papers.

Parental socio-economic status

Individuals who grow up in a low-status socio-economic environment are more likely to experience adverse life outcomes, including enduring health problems, and several measures of the concept have been used, with various inclusion of parents' education, income, residence, among other factors.

The same measure of parental socio-economic status (SES) was used in all papers, either as the main predictor (*Papers III, V, X and XII*) or as a possible confounding factor (in all other papers). It was collected at the 1-year examination and was based on points 0-5 for four factors in accordance with the social grouping of the Centre International de l'Enfance:[129] The occupation of the breadwinner (0 being labourers and 5 being a business or professional occupation), how the breadwinner earned his/her wages (0 being public relief and 5 being own business or capital), the education of the breadwinner (0 being basic schooling and 5 being attainment of a university degree), and the character of the living accommodation (according to its size and number of persons per room).[31] The resulting scale from 0 to 20 was originally transformed to a scale from 1 to 9 in order to save space on punch cards, with higher points indicating increasing SEP. In all papers, groups 8 and 9 were collapsed due to low frequencies in the upper group, and thus a 1–8 point scale was used.

One of the limitations of the measure is that only the breadwinner's situation is incorporated, and the other parent's occupation and education are not registered. Also, only one overall measure of parental SES is available, thereby preventing analyses that separate possible effects of occupation, education, and living accommodations. While the dissertation uses only the term parental SES to describe this measure, some of the included papers alternatively used parental social status and infant socio-economic status.

VI. Early predictors of intelligence

Summary

The dissertation contributes to the scientific literature on early predictors of intelligence in six papers. First by providing an overview of the relative importance of a broad selection of potential early predictors of IQ in adulthood. Second, it specifically addresses the prospective associations of developmental milestones and birth weight with IQ in adulthood.

Systematic studies of the relative contribution of early predictors of intelligence that include possible predictors from several domains are rare. We conducted the first study to compare the contribution of a broad selection of potential early predictors of intelligence in adulthood. Thus, based on a study of three non-overlapping samples, IQ was assessed at three different adult ages. Parental SES and sex explained 16.2–17.0 per cent of the variance in adult IQ. Other consistent predictors were related to physical (mainly head circumference) and behavioural characteristics (1- and 3-year milestones).

While substantial motor delays are often indicative of general developmental cognitive delays, studies focusing on associations between motor development and cognitive development in the ‘normal’ range of development are limited. Associations between motor development and intelligence have especially been found in cross-sectional studies of children, and we conducted the first prospective studies investigating a wide range of motor milestones in relation to IQ in adulthood. For both BPP and WAIS, faster attainment of several milestones, and especially the milestone ‘walking without support’ was associated with higher IQ in adulthood. For WAIS, we also found significant interactions of milestones with parental SES; thus, stronger associations were found for infants of parents with low SES compared to high SES.

Research of milestones attained between the ages of one to three years has especially focused on language development. The amount of empirical evidence supporting an association between language development and intelligence is convincing. However, the majority of studies are cross-sectional or investigate intelligence in childhood. Moreover, other milestones, attained in the second and third years of life, have been investigated less. In two studies, we investigated associations between 20 developmental milestones attained in this age period and IQ in adulthood and found that especially milestones related to language and social interaction were related to both BPP and WAIS. Moreover, we were the first to elucidate that milestones in infancy primarily show direct associations with adult IQ and only to a smaller extent are mediated by milestones attained in the subsequent years. In a third study based on the I-S-T 2000 R, we found that milestones related to language explained 6.7 per cent of the variance in IQ in midlife.

A considerable number of studies support associations between birth weight and intelligence, with the majority focussing on low birth weight groups. We conducted the first study examining birth weight in relation to IQ at three different adult ages. For all adult ages, mean IQ was increasing across the four lowest birth weight categories and declined for the highest birth weight category (more than 4 kg). All associations generally increased with the inclusion of gestational age as a confounding factor; this underlines both an effect of birth weight that is independent of gestational age and that associations between birth weight and intelligence may become stronger when the covariance with gestational age is taken into account.

Background

Individual differences in intelligence have been found to influence developmental trajectories across the lifespan, affecting psychological and health outcomes, including mortality,[12,54,130] and preserved intelligence has been suggested as a marker of successful ageing.[54] This has increased the interest in identifying factors that influence the development of intelligence.

The heritability of intelligence in 20th-century Western populations has been well established and is estimated to range between 0.40 and 0.70.[6] It is generally recognised that the genetic influences on intelligence increase across age, whereas the influence of shared environmental factors decreases.[131,132] A possible explanation of the increasing importance of genetic differences for individual differences in intelligence with age is that early in life cognitively stimulating experiences are primarily imposed (or not imposed) on the individual, showing up as an environmental influence. However, as individuals become more independent, they increasingly choose, modify, and create their own experiences and environment according to their genetic predispositions.[132,133] The effects of mobility and learning, therefore, enhance the effects of genotype on intelligence.

Historically, there has been great interest in identifying environmental influences on the development of cognitive abilities. This line of research has yielded important insights into possible predictors of especially childhood intelligence, namely social influences (e.g., family and peers), educational influences (e.g., educational level and training), biological influences (e.g., nutrition and exposure to chemicals), and prenatal factors (especially birth weight).[134-142] For many factors, it is, however, unclear whether they affect individuals over the full lifespan or only for a limited period in childhood or adolescence. It is thus possible that the effects of early-life factors are diluted as many other later exposures influence the individual. Conversely, although the influence of shared environmental factors has been found to decrease with age, it is also probable that the effects of early suboptimal development in some cases will increase over the lifespan (e.g., early cognitive skills may affect educational level which again affects IQ[143]).

The dissertation adds to this literature, first, by providing an overview of the contributions to adult intelligence of a broad selection of early predictors (*Paper XII)* and, subsequently, by focusing specifically on milestone development (*Papers IV, VII, VIII, IX*) and birth weight (*Paper VI*).

Early predictors and intelligence: an overview

Although several studies have investigated associations between early predictors during the first years of life and intelligence, general conclusions on the importance of each factor relative to others are difficult to draw. This is partly because the factors are often highly interrelated, which makes the interpretations and conclusions of the findings in each study dependent on the statistical models and the variables included in the models. One way to partly overcome this is to provide results, not only for one or a few selected predictors but to put equal weight on a range of potential factors and compare their relative importance in the same study.

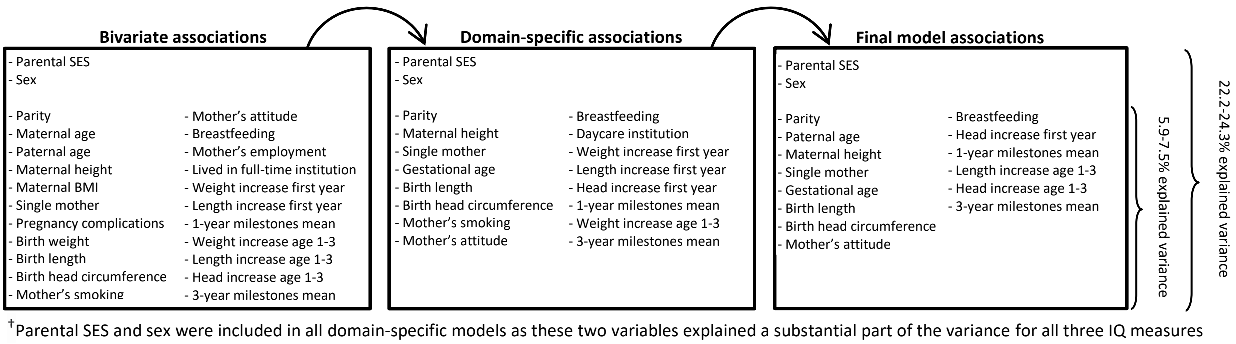
Empirical evidence

Studies have to a varying degree attempted to provide overviews of early predictors of intelligence by including a range of potential early predictors in specific domains to compare their relative contribution.[136-138,144,145] A study by Eriksen et al. (2013)[134] is the most inclusive according to the number of predictors and domains and provides a systematic evaluation of a broad selection of both well-established and less well-investigated predictors of IQ in a large sample of 5-year-old children. Parental education and maternal IQ were confirmed as core predictors of IQ, and together with sex, they explained 24 per cent of the variance in IQ.[134] Additional factors that primarily predicted IQ at age five were found to be parity, maternal BMI, birth weight, breastfeeding, and postnatal growth.

In *Paper XII*, we used the same strategy as Eriksen et al.[134] and thereby provided an overview of the importance of a broad selection of potential early predictors of intelligence in adulthood presented by three methodological approaches (illustrated in Figure 2). We compared the contributions to IQ of a broad selection of potential early predictors within the domains of: 'family background', 'pregnancy and delivery', 'postnatal influences', '0–1-year growth and behavioural development', and '1–3-year growth and behavioural development'. Three non-overlapping samples based on the CPC were utilised, and we found that the included early-life predictors explained 22.2–24.3 per cent of the variance in adult IQ.[146]

Significant bivariate associations were observed for 24 of the 28 predictor variables included in the study. In domain-specific analyses (in which all variables in each domain were analysed together), several patterns from the bivariate analyses were repeated, and variables from all five domains were significantly associated with IQ. The core predictor of IQ was parental SES which was consistently and markedly associated with adult IQ in all three study populations. In the final model (in which variables with a p-value of 0.10 or below in the domain-specific analyses were included), parental SES explained 16.2–17.0 per cent of the variance in IQ together with sex. Factors other than parental SES and sex explained between 5.9 per cent and 7.5 per cent with the most consistent being head circumference at birth, head increase in the first year, head increase from age one to three years, and three-year milestones.[146]

Figure 2. Predictors of IQ in adulthood (modified from *Paper XII*)[†]



[†]Parental SES and sex were included in all domain-specific models as these two variables explained a substantial part of the variance for all three IQ measures

The three approaches illustrated above yield different results, especially the final model, where only a limited number of variables were significantly associated with IQ. This is most likely due to the fact that the final model shows the direct effect of each variable and not indirect effects that were mediated by other factors. That may partly explain why factors that were significant in the bivariate- and domain-specific analyses did not continue being significant in the final model (e.g., weight increase that predicts milestone development in the first year of life).[108] *Paper XII* concluded that the strongest and most consistent early predictors of adult IQ, apart from parental SES and sex, were physical (head circumference at birth and growth in head size) and behavioural characteristics (1- and 3-year milestones). Interestingly, no noticeable changes in the strengths of associations were found in the three follow-up samples despite large age-differences at the time of IQ assessment.

Other studies have supported the importance of parental SES by showing that parental education, maternal IQ, social class at birth, and family income explain substantial parts of the variance in IQ in the offspring.[134,136-138,147] Correlations between parent's socio-economic status and their children's IQ have been estimated to be between 0.30 to 0.35,[6] which is slightly lower than what was found in *Paper XII* with correlations between 0.36 to 0.41. Sex differences on the Danish version of the WAIS were likewise found in a sample of 50-year-olds[148] where men performed significantly better than women, and similar results were found for IST-2000 R in the CAMB.[60] Conversely, a Danish sample of 5-year olds found the opposite as girls performed significantly better than boys on the Wechsler Preschool and Primary Scale of Intelligence.[134]

The predictive validity of anthropometric measures early in life for IQ has likewise been emphasised in other studies. Thus, especially birth weight has been shown to predict intelligence across the adult lifespan in both the CPC[139] (described in *Paper VI*) as well as in other studies,[144,145,149-156] but head circumference at birth has also been found to predict cognitive outcomes.[157] In *Paper XII*, head circumference at birth was among the strongest predictors of IQ, which may be interpreted in the framework of significant associations between head circumference, brain size, and intelligence.[47] Additionally, high inter-correlations among weight, length, and head circumference at birth were found (range 0.78–0.87), and co-linearity may explain why weight and length were not significantly associated with IQ in the final model. The importance of postnatal growth has also been reported in other studies.[47,144,158]

Generally, studies agree that a range of early predictors are associated with cognitive outcomes, and significant associations have, in addition to factors related to parental SES and physical size, especially been found for nutritional factors (including breastfeeding),[159-161] parental age,[136,137] parity,[162] maternal smoking,[163] physical growth,[158] and developmental milestones.[62,109,110,164] Combined, these results support the hypothesis that several early predictors during the first years of life are associated with adult intelligence and that a significant amount of variance in intelligence can be ascribed to factors in these first years. The relative importance of each predictor depends on the methodological frame in which it is investigated, but research generally agrees that among early environmental predictors, factors related to parental SES (e.g., education, occupation, and income) are the most important predictors for intelligence.

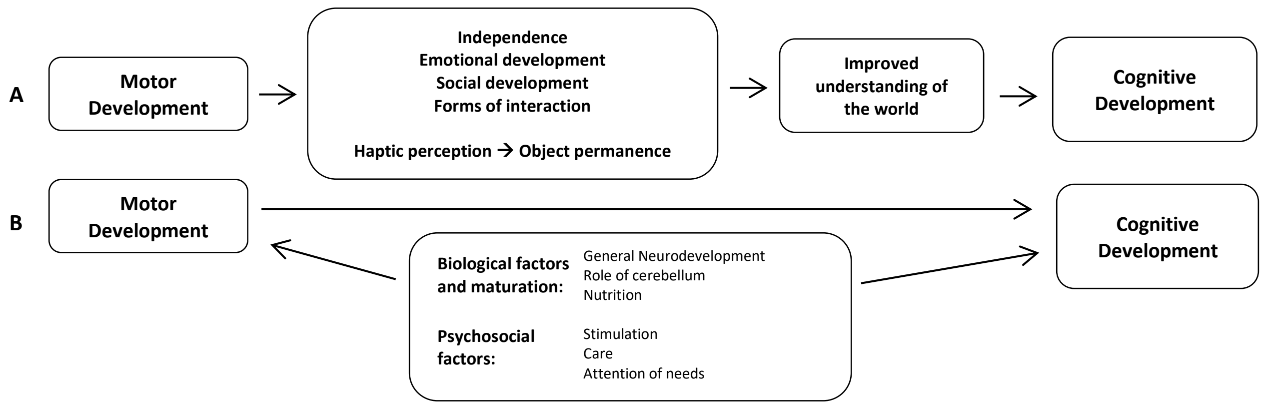
Finally, the importance of genetic factors should be underlined. Thus, most environmental factors, including SES,[165] have been shown to be influenced by genes, which to some extent may be explained by genotype-environment correlations in which experiences are correlated with genetic propensities.[165] The fact that parental SES, for example, predicts intelligence does not, therefore, provide unequivocal information on whether the effect can be attributed to genes or environment. Considering parental SES to be a proxy of parental intelligence,[4] findings of the importance of parental SES as a predictor of offspring IQ may reflect heritability of intelligence rather than illuminating the importance of the environment. Likewise, the importance of physical size and milestone development may, to some extent, reflect heritability of physical characteristics that also characterise individuals with higher or lower intelligence. Apart from the potential role of SES as an important predictor of genetic origin, it may also have an important role as a moderator of genetic influences on intelligence. Thus, SES has been suggested to interact with intelligence test scores and yield different estimates of heritability of intelligence within different SES strata.[166,167] Genes and environment may, therefore, both be important for the development of intelligence and interact in a complex fashion within and between generations.

While *Paper XII* yields an overview of early predictors of IQ, the results from *Papers IV, VI, VII, VIII,* and *IX* each add to the scientific literature by providing unique information on specific associations of intelligence with milestone development and birth weight.

Infant developmental milestones and intelligence

The assessment of milestones in the first year of life is generally often concerned with motor development. Historically, there have been different views on the relationship between motor skills and cognitive abilities in children. The majority, including Piaget, Dewey, and Locke, however, consider motor and cognitive development to be closely related.[104,168,169] Several theories have attempted to explain associations between motor and cognitive processes, and generally, two main hypotheses support a positive association between the two (Figure 3). The first is a causal explanation suggesting motor development to be a prime requisite for the cognitive development; thus cognition develops partly from motor skills because movement is important for the infant's ability to understand the world around it.[105,170-172] The second hypothesis suggests that milestones are markers of underlying confounding factors; thus that motor- and cognitive abilities both stem from the same underlying biological[173-176] and psychosocial factors.[6,177-180] However, at every point in motor development, perception guides motor behaviour by providing feedback about outcomes of recent movements and information about what to do next.[181] Thus, some basic perceptual-cognitive skills are a prerequisite of motor development.

Figure 3. Main hypotheses of the potential associations between motor and cognitive development

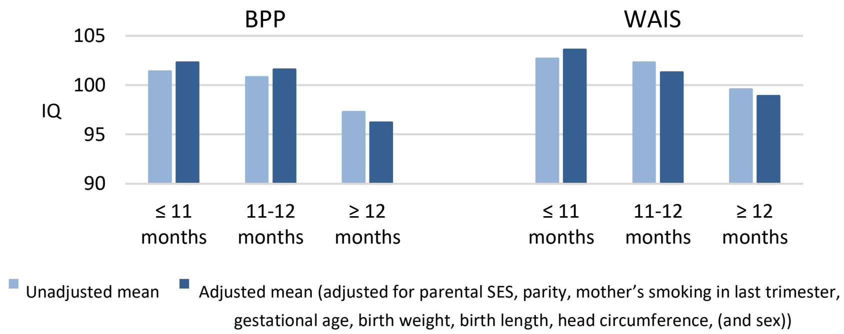


Empirical evidence

Substantial motor delays are often indicative of more generalised developmental delays or other disabilities,[182,183] and likewise, gifted children have been found to have a faster motor development than children who are not gifted.[184,185] Studies on infant developmental milestones and intelligence have primarily focused on outcomes in childhood and adolescence. The majority of these find that slower motor development in infancy is associated with suboptimal cognitive function in childhood (including different measures of IQ and educational outcomes);[186-190] and especially the age of walking has been found to be an important milestone. However, others find that these associations are small or inconsistent.[191,192] Studies of motor skills in the subsequent years also support a relationship,[193] and cross-sectional studies in adolescence found motor skills to be associated with academic outcomes[194] and working memory.[195] A review concluded that relationships between motor and cognitive skills generally were stronger in prepubertal children compared to pubertal children and that especially higher-order cognitive skills related to fluid intelligence were significantly correlated to motor skills.[196] Generally, however, previous studies leave several questions unanswered as they most often use selected samples of, for example, children with motor deficits, are cross-sectional, or only have a short follow-up interval. Potential associations of motor development with cognitive outcomes in adulthood are thus less elucidated. Three prospective studies have found associations between infant developmental milestones and educational level,[172] executive function,[197] and reading comprehension and fluency[198] respectively, but *Papers IV and VIII* were the first to study associations with IQ in adulthood.

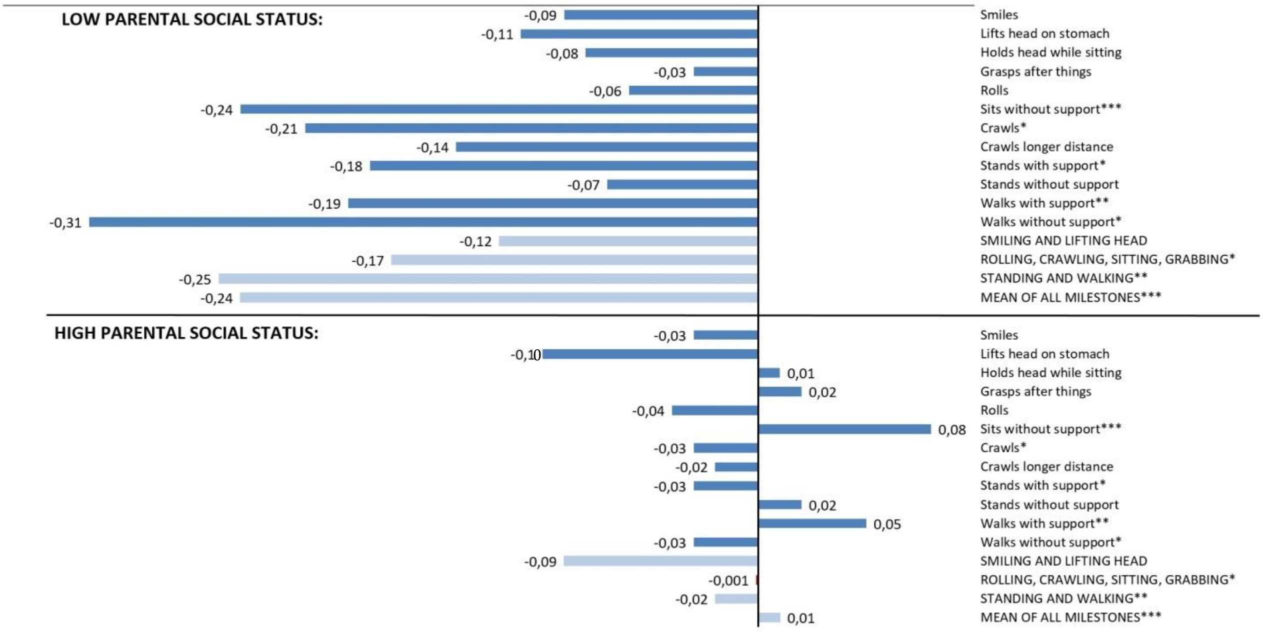
The papers found that later acquisition of a range of infant developmental milestones was associated with lower IQ measured with both BPP and WAIS.[109,164] Furthermore, they found that the single milestone most strongly associated with IQ was 'walking without support', which is illustrated in Figure 4.

Figure 4. Observed and adjusted means for IQ in relation to age of walking without support for BPP and WAIS (modified from *Paper VIII*)



Additionally, *Paper IV* found significant interactions of infant development with parental SES; thus, associations were significantly stronger in infants of parents with lower SES compared to higher SES, which is illustrated in Figure 5 according to performance IQ. Although effect estimates were generally small, the single milestone 'walks without support' accounted for 9.2 per cent of the variance in performance IQ in infants of low SES parents, suggesting considerable importance of this milestone in that group of children.[199] The study is the first to find such interactions. The results may suggest either that different mechanisms may operate in families with high and low SES with regard to the association between infant motor and cognitive development or, that certain mechanisms are stronger in some SES groups than others.

Figure 5. Standardised regression coefficients for infant developmental milestones and performance IQ[164]



Adjusted for sex, parental SES, parity, mother's cigarette consumption in last trimester, gestational age, birthweight, and birth length
*p≤0.05; ** p≤0.01; *** p≤0.001 (p-values illustrate the level of significance for the interaction term with parental SES)

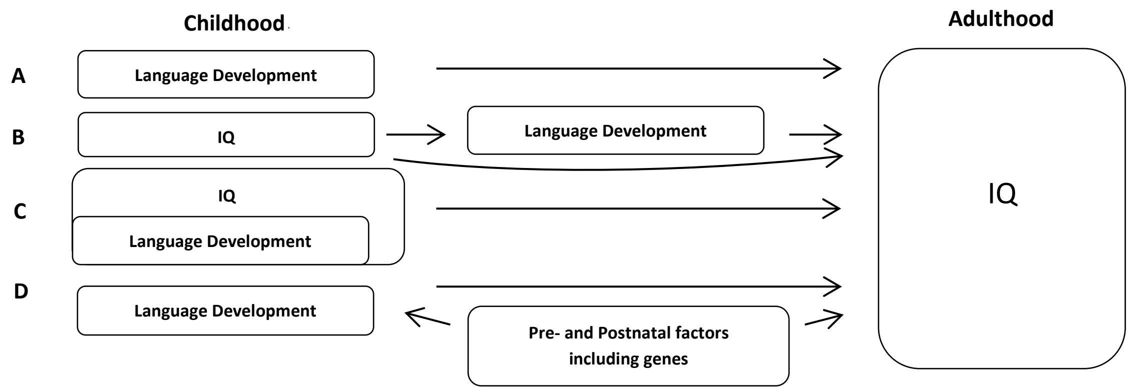
Combined, evidence supports that infant motor development is associated with adult intelligence. While previous studies thus support associations of infant motor development and cognitive outcomes in especially childhood and adolescence, *Papers IV and VIII* support the limited evidence that the associations persist into adulthood and that milestone development in the first year of life is associated with adult IQ. Importantly, *Paper IV* finds parental SES to modify the associations; however, more research should be carried out to corroborate these findings.

Milestones from age one to three years and intelligence

Research of milestones attained between the ages of one to three years has especially focused on language development. Though there are large variations even within the normal range of attaining language milestones, the attainment of expressive language has been found to be somewhat similar across countries.[200] Individual differences in language attainment have shown to be associated with a range of academic outcomes in addition to measures of intelligence.[172,201-209] The causal relationship between language and intelligence is not uncomplicated to investigate since they, in most cases, develop in parallel. However, four overall hypotheses of a relationship may explain how these associations occur (Figure 6).

According to the hypothesis of a causal explanation (A), language development exerts an influence on intelligence. Theoretically, this is supported by the theories of Vygotsky (1986)[116] and his thoughts of cognitive development resulting from the internalisation of language. In the situation of deaf children, a natural experimental design has been set up that empirically tests the causal relationship between language and intelligence.[210,211] In such studies, deaf children with deaf parents have been found to score higher on an IQ test than deaf children with hearing parents. Assuming that deaf parents teach their children to communicate at a younger age than hearing parents do to their children, the results suggest that language attained on schedule facilitates cognitive development.[212] Reverse causality as a potential explanation is illustrated by (B) in which early cognitive abilities are an important predictor of the speed of language development. This is supported by the severely impaired language development observed in individuals with intellectual disabilities[213,214] and evidence that vocabulary depends on processes of inference and reasoning.[6,215] The third explanation (C) questions the division of language and intelligence and suggests that language development is an essential aspect of early intelligence and that they both, therefore, exert an influence on adult IQ. This is in accordance with the fact that vocabulary is one of the best measures of crystallized intelligence[6] in addition to being one of the subtests in the WAIS with the highest correlation with the full WAIS scale.[57,58] Additionally, the idea of language being an essential part of intelligence is already incorporated in most tests of children's intelligence, as tests of language are most often included in one or several subscales.[50,216-219] Finally, as illustrated by (D), common causes such as prenatal (e.g., birth weight and gestational age)[154,220-223] or postnatal factors (e.g., attachment, preference for novelty or family size)[224-226] could affect the development of both language and intelligence. Shared genetic factors may also exist as genetic factors have been found to influence children's speech, also in typical development.[227,228]

Figure 6. Main hypotheses of associations between language development and intelligence†



†In adults, language and cognition are obviously closely related. Thus, language could have been included in the circle of IQ in adulthood

Empirical evidence

Although the causality of the relationship between language and intelligence is less clear, the empirical amount of evidence supporting an association is convincing. Thus, individual differences in the timing of language milestones have been found to be associated with a range of cognitive outcomes, ranging from math skills,[209] reading difficulties,[203,205,207,208] and academic abilities in general[172,208,229] to problem-solving[201] and intelligence.[204,206,207,230] However, the vast majority of studies are based on cross-sectional designs or outcomes in childhood, while studies of the potential associations into adulthood are scarce.[231] Likewise, there is a lack of studies investigating not only language but also other milestones attained in the same age period. In *Papers VII, VIII* and *IX*, we contributed to the scientific literature by investigating associations between 20 developmental milestones attained during the second and third years of life and intelligence at three different adult ages.

Paper VII focused on 20 developmental milestones attained during the second and third years of life and investigated associations with WAIS in adulthood. The milestones were related to language, walking, eating, dressing, social interaction, and toilet training. It was found that younger age at attainment of several milestones was significantly associated with higher IQ. Especially milestones related to language and social interaction were important, and together they accounted for 4.6 per cent of the variance in full-scale IQ. Associations with verbal IQ were generally stronger than associations with performance IQ.[109] In *Paper VIII*, we conducted analyses of all 32 milestones attained in the first three years of life with both BPP and WAIS. The results for BPP supported the results from *Paper VII* as especially later attainment of milestones related to language and social interaction were significantly associated with lower IQ. Additionally, later attainment of milestones related to dressing were significantly associated with higher IQ.[110]

Based on the results from *Papers VII and VIII*, a focus on language was chosen in *Paper IX*, where the outcome was I-S-T 2000 R measured in midlife. The results supported the findings from the two previous papers as significant associations were found between language development and intelligence. Milestones related to language explained 6.7 per cent of the variance in IQ while milestones related to social interaction explained 3.1 per cent.[62]

In *papers VII, VIII*, *and IX*, the strongest associations with IQ were found for the three single milestones ‘naming objects/animals in pictures’, ‘forming a sentence’, and ‘sharing experiences’. Table 8 shows regression coefficients for these milestones in predicting IQ at the three follow-ups.

Table 8. Standardised regression coefficients (unadjusted) for milestones predicting level of IQ at three different follow-ups (modified from *Papers VII, VIII, and IX*)

	MDB BPP	**PDP WAIS**†	**CAMB I-S-T 2000 R**
	Unadjusted β	Unadjusted β	Unadjusted β
Naming objects/animals in pictures	-0.19***	-0.23***	-0.14***
Forming a sentence	-0.19***	-0.20***	-0.10**
Sharing experiences	-0.16***	-0.20***	-0.17***

*** $p<0.001$

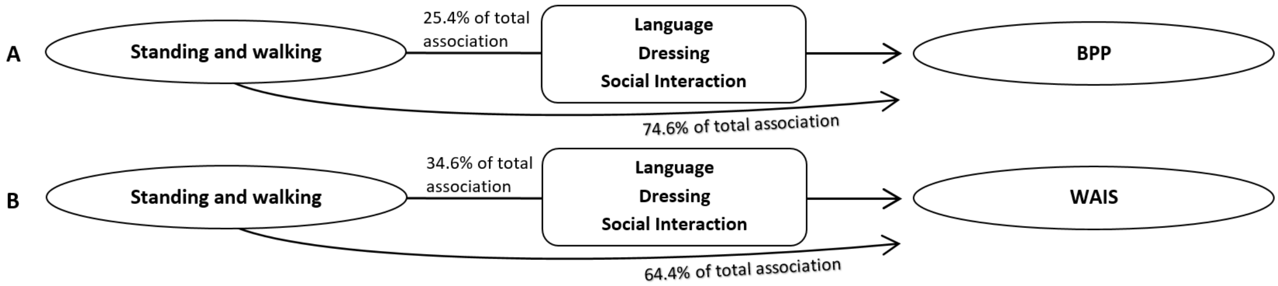
†For comparison reasons based on non-imputed values and, therefore, not completely identical with estimates in paper VII

Taken together, these empirical findings support an association between language development and intelligence. While previous studies mainly support this association in childhood and adolescence, *Papers VII, VIII*, *and IX* establish evidence that these associations also exist in young adulthood and midlife. Thus, faster attainment of language milestones in the first three years of life is associated with a higher IQ in adulthood, and this association persists over time. Milestones related to language and social interaction were by far the most important for IQ compared to milestones related to other areas attained in the same age period. However, the mechanisms of these associations are yet to be understood.

The interplay between early and later milestones

By focusing on all milestones from birth until the age of three years in the same study, *Paper VIII* enabled us to conduct analyses of mediation effects. In analyses of indirect and direct associations of the milestone means with BPP and WAIS, the milestone mean Standing and walking showed the strongest associations with IQ. However, the direct association was significant only for BPP, although the coefficients were similar.[110] For both BPP and WAIS models, the direct association of Standing and walking with IQ was stronger and accounted for more of the total association than did the indirect associations, which is illustrated in Figure 7.

Figure 7. Percentage accounted for by direct and indirect associations of standing and walking with BPP and WAIS respectively (modified from *Paper VIII*)



The idea of language as a mediating factor in the association between motor development and intelligence is supported, although not directly investigated, in other studies. Thus, it has been suggested that walking elicits changes in exploratory behaviours and interactions with objects that may encourage joint-attention episodes and communication with caregivers.[232,233] Accordingly, early attainment of walking has been associated with faster language development (vocabularies and receptive language).[232-237] In *Paper VIII*, we likewise observed significant associations of the mean Standing and walking with Language and Social interaction and play. In sum, the paper adds to the literature by showing that motor development in infancy primarily shows a direct association with adult intelligence that only to a smaller extent is mediated by development attained in the subsequent years.

Birth weight and intelligence

Birth weight has, among other outcomes, been studied in epidemiological research with respect to cognitive abilities, especially in childhood,[154] with the majority of studies focusing on clinically low birth weight groups.[220] Additionally, studies investigating associations between birth weight and intelligence in adulthood are generally scarce and also more inconclusive than those on intelligence in children.[145,150,151]

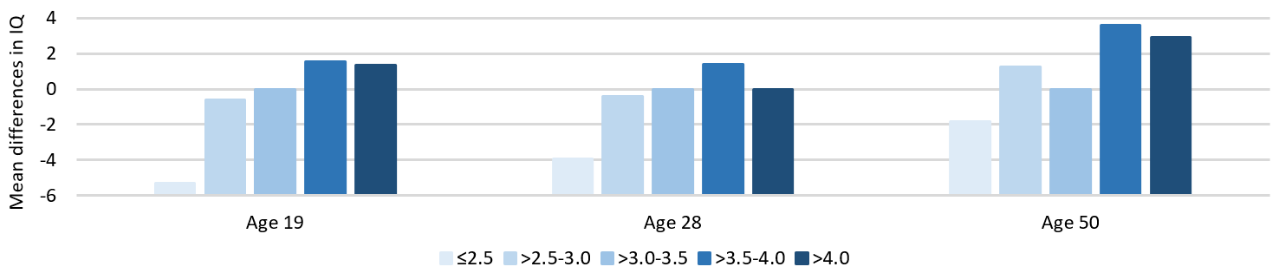
Interpreting associations between birth weight and cognitive outcomes is challenging and has been suggested to be linked to a series of methodological limitations.[238] One explanation stresses the importance of confounding factors that influence both birth weight and intelligence such as genetic factors,[239,240] nutrition (including the DOHaD hypothesis),[20,241-243] or insulin-like growth factors.[244-246] Also, there may be direct influences of fetal growth on cognitive development that are independent of prenatal factors; such an effect may be mediated through frequent illnesses or aspects of parent-child interactions associated with individual differences in birth weight.[139]

Empirical evidence

A recent meta-analysis based on 57 eligible studies concluded that individuals with low birth weight had 10–11 points less in IQ score (4–26 years in age) compared to individuals with normal birth weight, and a gradient relationship between different levels of low birth weight and IQ was also demonstrated.[220] However, the majority of the included studies focused on outcomes in childhood and young adulthood and also, conclusions were not drawn on the full range of birth weights.

In *Paper VI*, we utilised data from the CPC to address the relation between birth weight and IQ at three different adult ages in the full range of birth weights. We found birth weight to be significantly associated with IQ at all three follow-up assessments between the ages of 19 and 50 years. More specifically, IQs were increasing across the four lowest birth weight categories and declined (although not statistically significant) for the highest birth weight category.[139] The study was specifically highlighted in a recent review[220] for controlling for a wide range of confounders compared to other studies; these included sex, parental SES, mother's age at birth, birth order, and mother's smoking in last trimester. Inclusion of these confounders did not change the interpretations of the results. In contrast to most previous studies, gestational age was also adjusted for in separate analyses, which generally increased the strengths of all associations; this suggests an effect of birthweight that is independent of gestational age and that the association may become stronger when the covariance with gestational age is taken into account.

Figure 8. Adjusted mean differences in standardised IQ scores for each birth weight category compared with the middle birth weight category for tests at mean ages of 19, 28, and 50 years (modified from *Paper VI*)



Adjusted for sex, infant SES, mother's age at birth, birth order, mother's smoking in last trimester, and gestational age

Our findings suggest that the cognitive influences of birth weight tend to be stable until midlife; thus, that the effects of environmental factors in postnatal life are not strong enough to overshadow effects of genes or the intrauterine experiences on cognitive outcomes. The stable long-term effects of birth weight until midlife are in line with a study by Raikkonen et al. (2013) who found lower birth weight to be associated with lower cognitive ability in 68-year-olds in a male sample from the Helsinki Birth Cohort Study.[247] In contrast, Richards et al. (2002) found no associations between birth weight and intelligence in 43-year-olds in the British 1946 cohort[152] and neither did Martyn et al. (1996) in a population of 48-74-year-olds born in England.[150] The influence of birth weight on intelligence at later ages in *Paper VI* was mainly explained by the effect of birth weight on intelligence at earlier ages, which is in accordance with the understanding of intelligence as a stable mental characteristic through life.[6] Whether the associations in the study reflect a direct influence of fetal growth on intelligence or they reflect confounding factors not included in the study (such as genetic factors or maternal circumstances during pregnancy) is not evident.

Combined, these findings support associations between birth weight and intelligence in adulthood, not only for individuals with low birth weight but in the full range of birth weights. In our study, the associations did not diminish over the life course (up to midlife); however, more studies with repeated follow-ups are needed to confirm this finding.

Methodological considerations

Papers IV, VI, VII, VIII, IX, and *XII* investigating early predictors of intelligence are all prospective studies, which provides several strengths. Thus, in all papers, the data on early predictors were collected very close in time to the actual timing of the specific predictor. Only data on the 3-year milestones were collected retrospectively, and this was done at the 3-year examination, which is still close in time to the attainment of these milestones. Additionally, data on intelligence were available at three different adult follow-ups between the ages of 19 and 50 years, and the follow-up times between the early predictors and intelligence are in themselves a distinctive feature in all the papers that add substantial contributions to the literature.

Selection bias

As described in Chapter III, the CPC is a selected birth cohort characterised by higher frequencies of complications in addition to higher frequencies of single mothers. Moreover, especially the 3-year follow-up in addition to the PDP and CAMB examinations are characterised by a relative overweight of individuals with high parental SES. The study populations in all the papers, therefore, differ from the full CPC cohort by higher parental SES, which may have resulted in an overrepresentation of individuals with a higher IQ. In *Paper IV*, significant interaction effects were found with parental SES for associations between infant developmental milestones and IQ. However, such interactions were not found in the other studies, suggesting that selection bias may not be a substantial problem.

The PDP is a selected sample with an overweight of individuals exposed to steroid hormones and barbiturates. Phenobarbital exposure during early development has been shown to have long-term harmful effects on cognitive development; thus, men exposed prenatally to phenobarbital were found to have significantly lower verbal intelligence scores (approximately 0.5 standard deviations) than predicted.[248] However, in all papers, interaction effects with prenatal exposure to medication were tested and found non-significant, suggesting that the selection of the PDP sample did not influence the associations found in each study.

Different measures of intelligence

In the papers on milestone development, WAIS was used in *Papers IV, VII, and VIII*, BPP was used in *Paper VIII*, while IST-2000 R was used in P*aper IX*. In *Papers VI and XII* on birth weight and early-life predictors, all three measures of IQ were used. High intercorrelations between the scales (0.76–0.81; see Chapter IV) were found, but the instruments are three different tests that are not directly comparable.

Since three different IQ tests were used in *Paper IX* on birth weight, the results of the conditional regression models may have been influenced. Also, the standardised scores based on the three different samples may not be comparable. In *Paper XII*, the three study samples were independent, and general conclusions were drawn based on patterns for all three IQ outcomes, which is considered to be a considerable strength in such a study.

In the papers on infant developmental milestones, the interaction found in the WAIS sample for parental SES was not replicated in the BPP sample. This may reflect differences in the two measures; however, they correlate 0.81, which suggests that other factors may explain the interaction. The BPP sample included only men, and the mean age was younger, but there are no obvious reasons why this would explain an interaction effect. Additionally, the studies based on the WAIS showed that infant motor development was especially associated with later performance IQ compared to verbal IQ,[164] while language milestones were associated to a higher degree with verbal IQ.[109] These tendencies were not replicable with BPP and IST-2000 R as these tests were not as clearly divided into verbal and nonverbal scores, and also, information on BPP subtest scores was not available at all. However, the fact that significant associations were found for all three measures strengthens the overall conclusions of significant associations between early developmental milestones and intelligence.

Unmeasured confounding

To counteract the risk of bias due to confounding, the covariates included in the statistical models were carefully considered, with the premise for inclusion being that they should be theoretically possible common causes of both exposure and outcome. Generally, it was chosen to present several models of the multivariate analyses in order to interpret the contribution of the different covariates, which varied in the six papers but were all related to family background, pregnancy and delivery, postnatal influences, 0–1-year growth and behavioural development, and 1–3-year growth and behavioural development. Nevertheless, a possible limitation in all six papers is the likelihood of unmeasured confounding factors. The composite measure, parental SES, was included as a covariate in all papers, and one assumption could be that parental SES indirectly reflects environmental variation. Thus, children from homes with higher parental SES may have experienced a richer and more nurturing environment than children from homes with lower parental SES. However, children's experience and thus proximal factors are better captured by measures of the home environment that are designed to measure specifically designated patterns of nurturance and stimulation available to children in the home. One such measure is the Home Observation for Measurement of the Environment (HOME),[249-251] which includes dichotomous scores on, for example, frequent contact with a relatively small number of adults, a positive emotional climate, structure and order in the daily environment, and a minimum of social restrictions on exploratory and motor behaviour.

The included covariates mainly reflect distal factors such as, for example, parental SES, and the inclusion of more proximal factors may have added to the interpretation of the findings by elucidating potential mechanisms. However, with the behavioural genetic research questioning the long-term effects of shared environmental factors and the home environment,[132,133] it is also possible that inclusion of such factors would not have added considerably to the interpretation of the findings. Finally, the importance of genetics should be underlined. Genome-wide association studies have identified inherited genome sequence differences accounting for between 20–50 per cent of the heritability of intelligence,[252] and also, genetic effects on milestones[253,254] and birth weight[255] are apparent. Lacking information on maternal IQ is a strong limitation in all six studies as this has been found to be a predominant predictor of childhood IQ.[134] Assuming maternal IQ also to be highly correlated with the predictors in the papers, lack of adjustment for this factor is likely to have biased the estimates and to have induced residual confounding. Adjustment of maternal IQ could also be considered an indirect adjustment of genetic influences. Considering parental SES to be a proxy of parental intelligence,[4] adjustment for this covariate is, however, a partially and indirect control of genetic factors.

VII. Early predictors of personality

Summary

The dissertation contributes to the scientific literature on early predictors of personality in four papers by addressing prospective associations between developmental milestones, physical size and parental SES in early life, and personality scores in adulthood.

Infants and children who are markedly late in achieving developmental milestones in the first years of life are at higher risk for subsequent diagnoses of learning disabilities and some psychiatric disorders, and evidence supports the hypothesis that milestone attainment, even within the 'normal' range can be associated with personality. We conducted the first study to investigate the timing of motor developmental milestones in the first year of life and personality scores in adulthood and found that later attainment of sitting without support, crawling, and walking with and without support were associated with increased neuroticism in adulthood. Additionally, we conducted the first study to find that the timing of language milestones was associated with personality scores in adulthood; more specifically, that faster attainment of language milestones was associated with lower neuroticism in young adulthood and with higher extraversion and openness to experience in midlife.

While evidence supports associations between suboptimal pre- and postnatal growth and a range of adult somatic and mental health outcomes, limited empirical evidence exists that lends support for associations between the physical size in early life and personality in adulthood. Relationships between low birth weight and scores on the lie-scale have been suggested, and we replicated these findings by observing significant associations between smaller size at birth, at one year, and three years of age, and a higher score on the EPQ lie-scale. However, these associations were observed only in men.

Individuals who grow up in a low-status socio-economic environment are more likely to experience adverse life outcomes, including enduring health problems, and several studies support mechanisms that may explain a potential link between parental SES and personality in the offspring. We found that higher parental SES at the age of one year was associated with lower neuroticism, higher psychoticism, and lower lie-scale scores in adulthood; however, these associations were all mediated by intelligence whereby no direct associations between parental SES and personality trait scores existed. Recent evidence has supported these findings, and the combined empirical evidence supports the hypothesis that parental SES early in life is associated with personality traits in adulthood, although the associations seem to be mediated by intelligence and education.

Background

Individual differences in personality have been associated with many outcomes of interest, including physical and psychological health,educational and occupational achievements, and social relationships[79,256-258] with effect sizes of some outcomes comparable to those of socio-economic status and cognitive ability.[7]

It is recognised that both genetic and environmental factors influence personality development. Personality traits in childhood are often thought to emerge or develop from temperament,[259,260] whereby specific aspects of temperament such as reactivity and regulation combine to define the constructs of extraversion, negative affect, and effortful control.[256,261] Studies of childhood trajectories have suggested that personality traits are less distinctive in early childhood than they are later[78,79] and also that the stability of traits increases with age.[70,78] Especially mean-level changes have been observed across the lifespan.[262,263]

Much research on personality traits in adulthood has focused on their trajectories[264] or how life events,[263] intelligence,[265,266] or other personality traits are associated with such trajectories.[267] Another line of research concerns the aetiology of personality traits, utilising different research designs to decompose trait variance into that of genetic and environmental origin. Results of most of these studies support the conclusion that personality traits are moderately heritable and also that shared environmental influences account for very little or no variance in most personality traits of adults.[268,269] The importance of early-life factors for adult personality traits have, nevertheless, been proposed by several theories (e.g., Freud's on psychosexual stages of development[270] and Bowlby's on attachment[271]). However, the empirical evidence on the importance of specific environmental factors is characterised by a lack of studies following the same individuals from early childhood to adulthood.

The current dissertation adds to this literature by examining three main predictors of personality in adulthood, namely milestone development (*Papers I and XI*), physical size (*Paper II*), and parental SES (*Paper III*).

Milestones and personality

Infants and children markedly late in achieving developmental milestones in the first years of life are at higher risk for subsequent diagnoses of learning disabilities and some psychiatric disorders.[198,272,273] The evidence of a link between the timing of developmental milestones and personality in adulthood is less clear; thus, no previous studies have specifically investigated this. *Papers I and XI* address the relationship between various milestones attained in the first three years of life and personality in adulthood. While *Paper I* focuses on motor developmental milestones attained in the first year of life, *Paper XI* focuses on language development in the subsequent years. A number of mechanisms are likely to explain why such associations would exist.

Firstly, there may be a causal effect of early development on personality where the timing of motor and language development affects the development of certain personality traits (e.g., that children who learn to talk early have increased opportunities to engage in social interaction, which may increase their tendency to develop facets related to extraversion and openness). Secondly, associations may reflect reverse causality (e.g., that the temperament of the child affects the timing of motor development[274]). Thirdly, they may reflect recurrent mutual interactions between early development and personality where certain personality traits facilitate early attainment of milestones, and faster attainment of these milestones contributes to the development of certain personality traits. Finally, common causes may affect both milestone development and personality. Potential common causes include genetic factors and proximal factors such as the home environment and parent-child interaction.[254,268,269,275-277] Empirical evidence of associations between milestones and personality is described below.

Motor developmental milestones and personality in adulthood

Evidence supports associations between motor developmental milestones in the first year of life and psychopathology in adulthood. Thus, a recent meta-analysis concluded that delayed sitting, standing, and walking unsupported were associated with increased risk of schizophrenia,[278] and delayed motor development has also been found to be associated with alcohol use disorders[279] and with other psychiatric disorders.[272] A high score of the personality trait neuroticism has been linked to psychopathology;[280-282] however, associations of motor developmental milestones with personality traits have not previously been investigated.

In *Paper I*, we were the first to show that later attainment of motor developmental milestones in the first year of life was associated with increased neuroticism (measured by EPQ) in adulthood. We thus found that individuals who grew up to have high scores on neuroticism were more likely to sit without support, crawl, and walk with and without support later than individuals with low scores on neuroticism.[283] These findings were also reflected in the findings on milestone means, as illustrated in Table 9. A total of 2.8% of the variance in neuroticism scores were explained by the 12 included milestones.

The associations were adjusted for sex, single-mother status, parity, mother's age, father's age, parental SES, age at follow-up, and birth weight. Additional analyses adjusted for intelligence, which is a possible intermediate factor on the causal pathway between motor development and personality; however, the estimates did not change considerably with the inclusion of intelligence or any of the other covariates. Extraversion was significantly associated only with one milestone (crawling a short distance) while no significant associations were found for psychoticism with any of the milestones.

Language milestones and personality in adulthood

Associations between language milestones and personality have been investigated only in children. Cross-sectional studies have found associations between smaller vocabularies and shyness,[284,285] high emotionality,[286] and low extraversion.[287] Some cross-sectional studies do, however, conclude that there are no associations between child personality characteristics and language development.[288,289] Longitudinal studies have mainly focused on the causal link between personality characteristics and later language skills. These studies together conclude that several personality characteristics, including temperament, extraversion, and shyness,[287,290-292] are associated with later language abilities. However, no longitudinal studies have investigated whether early language development is associated with adult personality traits.

In *Paper XI*, we were the first to show that the timing of language attainment is associated with personality trait scores in adulthood. By utilising information on six language milestones together with information on EPQ and NEO-FFI collected in young adulthood and midlife, faster attainment of language milestones was found to be associated with lower neuroticism in young adulthood and with higher extraversion and openness to experience in midlife. Adjustment for IQ (additional to other potential confounders) attenuated the associations with openness while it did not affect the associations with neuroticism and extraversion.[94] Only modest amounts of variance in the personality trait scores of neuroticism, extraversion, and openness in adulthood (1.6–2.5%) were explained by language milestones; however, the study adds to the literature by suggesting a link between the two. The importance of both motor and language milestones for neuroticism is shown in Table 9.

Table 9. Standardised regression coefficients (unadjusted) for milestone means predicting level of adult neuroticism (modified from *Papers I and XI)*†

	Neuroticism (EPQ) Unadjusted β
Infant motor development (1-year mean)	0.10**
Smiling and lifting head	-0.01
Rolling, crawling, sitting, and grabbing	0.08*
Standing and walking	0.09**
Language milestones (language mean)	0.08*

*<0.05, **<0.01,*** <0.001

†From full information maximum likelihood models

In summary, the findings suggest that development in the first years of life is associated with personality in adulthood. Thus, that later motor development in the first year and later language development in the subsequent years are associated with the personality trait of neuroticism in young adulthood. Furthermore, faster attainment of language milestones may be linked to extraversion and openness to experience in midlife; however, no other studies have investigated these associations wherefore more research is warranted to establish any conclusions.

Physical size in early life and personality

Evidence supports associations between suboptimal pre- and postnatal growth and a range of adult somatic and mental health outcomes.[28,122,123,125,126,293-295] Several mechanisms are likely to explain why associations between physical size and personality also exist. Possible biological mechanisms include a shared genetic basis of growth and personality traits[296-298] and the DOHaD hypothesis,[19,20] where suboptimal fetal conditions (e.g., suboptimal growth) may alter the structure and function of cells, organs, and tissues, including the brain. Environmental adversities in early life (e.g., malnutrition, inflammation. or poorer economic circumstances in general) may also influence growth,[299-301] leading to changes in brain development and can thus offer an additional biological pathway through which physical size and personality may be associated. A possible psychological mechanism is that physical size may interact with the environment in shaping the developing personality through inducing different environmental reactions to the body size.[302] Evidence for such psychological interactions has been found, for example, for preterm[303,304] and obese children.[305,306]

Empirical evidence

Low birth weight has been found to be associated with personality in adulthood. Thus, associations have been found between low birth weight and higher neuroticism, higher agreeableness, and lower extraversion, in addition to antisocial behaviours[307-309] and being cautious, shy, and risk aversive.[310] Moreover, it has been found in two studies that low birth weight was associated with higher lie-scale scores.[309,310] Postnatal growth has been associated with trait anxiety[311] and schizotypal traits in young adulthood,[312] and associations of adult BMI and personality traits have been suggested, concluding that higher BMI is associated with higher extraversion and lower openness to experience.[313]

Although the existing research literature suggests that physical size may be associated with personality traits, there is a lack of prospective studies focusing on the physical size in early life in addition to studies that include successive measures of size. We have contributed to this literature with a prospective study in which we addressed the relationship between physical size early in life and personality in adulthood. In *Paper II*, we thus addressed the prospective relation of size in infancy and childhood with personality in adulthood, utilising measures of weight, length, and head circumference at birth and at the ages of one, three and six years in addition to EPQ (including the lie-scale) in adulthood.

For males, we observed significant associations between smaller size at birth, at one year and three years of age, and a higher score of the EPQ lie-scale. Thus, male infants with a lower weight, length, and head circumference at birth and the following three years generally attained higher scores on the lie-scale in young adulthood. None of the measures of physical size at six years was significantly associated with the lie-scale. The majority of associations stayed significant after inclusion of covariates; however, adjusting for previous growth generally resulted in weaker and most cases non-significant estimates. Likewise, adjusting for adult IQ attenuated several of the associations, suggesting that intelligence may act as a potential mediating factor.[314] Table 10 illustrates the standardised regression coefficients (only unstandardised coefficients are shown in *Paper III)*.

Table 10. Standardised regression coefficients for childhood measures of weight, length and head circumference in models predicting adult lie-scale scores in men (modified from *Paper III)*

	Lie-scale (EPQ) Unadjusted β	**Lie-scale (EPQ)** Fully adjusted† β
Birth weight	-0.11**	-0.09
Weight 1 y	-0.18**	-0.15**
Weight 3 y	-0.13*	-0.11**
Birth length	-0.10*	-0.10*
Length 1 y	-0.12*	-0.11*
Length 3 y	-0.12*	-0.13*
Birth head circumference	-0.13**	-0.11*
Head circumference 1 y	-0.08	-0.08
Head circumference 3 y	-0.11*	-0.12*

*<0.05, **<0.01,*** <0.001

†Adjusted for single-mother status, parity, mother's age, father's age, parental SES, and age at EPQ measurement

A few significant associations were found for size with extraversion and psychoticism in women only, and these became non-significant after adjustment. No significant associations with physical size were found for the lie-scale in women.[314]

The results are thus in accordance with previous studies finding that lower birth weight is associated with higher lie-scale scores;[309,310] however, we found significant results only for men. Additionally, we showed that not only weight but also the length and head circumference were of importance and that not only birth size but also size in the subsequent years were significantly associated with the lie-scale.

Taken together, these empirical findings support an association between physical size and the EPQ lie-scale. However, inconsistencies exist as to whether physical size at birth and during the first years of life is associated with other personality traits. While previous studies suggest such associations, our findings give no support to the hypothesis that size in early life affects the other EPQ personality traits or that any associations exist for women.

Parental SES and personality

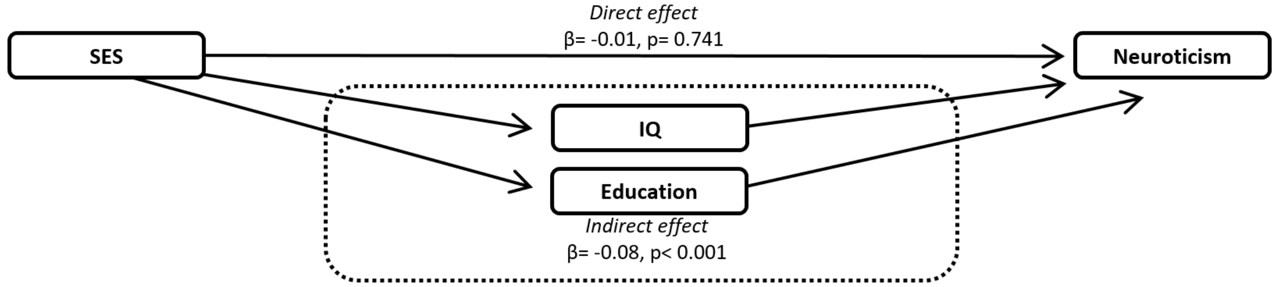
Individuals who lived in a low-status socio-economic environment early in life are more likely to experience adverse life outcomes, including enduring health problems.[315-317] A major challenge has been attempting to explain why these health disparities exist, and the importance of both intelligence and personality has been suggested as causal pathways.[11,318,319]

Several mechanisms are likely to explain why links exist between early-life SES and personality in adulthood. Parents with more years of education may be able to offer their children more support, perhaps leading to the development of specific traits.[320] Thus, parental education is a strong predictor of offspring educational attainment,[321] and to the extent that education is associated with specific traits,[93] it may be one mechanism through which parental SES may affect personality. By extension, intelligence may be a mediating factor on the path between parental SES and personality. Second, parents with higher SES may be more likely to have stable employment, which may promote the development of mature character development of, for example, self-directedness and cooperativeness[322] and less anxiety, including lower levels of neuroticism in the offspring.[320] Additionally, parents with sufficient economic means may be able to provide opportunities that promote the development of some traits, for example, life experiences (e.g., travelling) that may foster greater openness.[320] Finally, it is possible that associations between parental SES and offspring personality may be attributable to shared genetics across generations and between education and personality,[320] as genetic overlap has been found between the two.[323]

Empirical evidence

In *Paper III*, we found that higher parental SES at the age of one year was associated with lower neuroticism, higher psychoticism, and lower lie-scale scores measured with EPQ in adulthood.[199] However, analyses of mediation found no direct effects of parental SES on any of the adult personality trait scores but significant indirect effects mediated by IQ and education (number of years in primary and secondary school). A total indirect effect of the two factors was, thus, significant for neuroticism, psychoticism and the lie-scale, and IQ appeared to be the main mediating factor.[199] Figure 9 presents the results of neuroticism.

Figure 9. Direct and indirect effect of parental SES on neuroticism (modified from *Paper III*)



Data on IQ, education, and personality were collected at the same time, which raises the issue of the time course of these individual differences. The decision to include intelligence and education as mediators was based on evidence of significant stability of IQ through most of the lifespan,[53,54] in addition to an assumption that participants had finished their highest level of school education at the time of data collection.

The findings are partly supported by a recent study that meta-analytically combined results from seven samples (N>60,000) and found that parents with more years of education had children who were more extraverted, open, and emotionally stable as adults.[320] Additionally, a study of adults found that those who had parents with higher education had higher extraversion and openness scores and also that father's educational attainment was associated with greater emotional stability.[319] In adulthood, personality traits have been found to be associated with both education[324] and intelligence,[266] which was also found in *Paper III* where negative associations were found for neuroticism and the lie-scale, and positive associations were found for psychoticism, in relation to both IQ and length of education.

The results of *Paper III* support the mechanism of intelligence and educational attainment being intermediate factors on the causal pathway between parental SES in early life and personality. The above-mentioned meta-analysis additionally analysed potential mediators of the association between parental education and adult offspring personality.[320] Following the results from *Paper III*, they found that offspring IQ and education were consistent mediating factors in addition to income. Analysing differences in mediators according to adopted and non-adopted subsamples they found similar associations in the two groups, suggesting that effects of parental education on offspring personality might have been transmitted through the environment rather than through genetics.[320]

Combined, these results corroborate the hypothesis that parental SES early in life is associated with personality traits in adulthood, but the associations may partly or fully be mediated by factors related to adult intelligence and educational level.

Methodological considerations

Papers I, II, III, *and XI* that investigate early predictors of personality are all prospective studies, providing a number of strengths as described in Chapter VI. Additionally, data on personality traits were assessed in young adulthood (*Papers I, II, III*, *and XI)* and midlife (*Paper XI)*, and the time spans between early-life factors and personality measures are a unique characteristic of all the studies that add substantial contributions to this area of research.

Selection bias

As previously described, the CPC is a selected birth cohort. Moreover, especially the follow-ups are characterised by a relative overweight of individuals with high parental SES. The study populations in all four papers, therefore, differ from the full CPC cohort by higher parental SES, which may have resulted in an overrepresentation of individuals with certain personality traits (e.g., lower neuroticism and higher lie-scale scores).[199] There are, however, no obvious reasons why associations between early predictors and personality would be different in non-participants and that selection bias would have occurred. This is supported by the fact that interaction terms with parental SES were investigated in all papers and found to be non-significant. Likewise, interaction terms were investigated with regard to prenatal medication, and as no interaction terms were significant, the selection of the PDP sample is not assumed to have had a substantial influence on the associations found in the studies of personality.

Measures of personality

While the EPQ was used in all four papers, the NEO-FFI was used in *Paper XI* together with EPQ. Danish data with simultaneous administration of the EPQ-R and NEO-PI-R suggest correlations of 0.76 for both neuroticism and extroversion,[95] and also, EPQ and NEO-FFI have shown robust psychometric properties.[83,84,98] The personality traits of psychoticism and the lie-scale included in the EPQ have, however, been questioned.[85-87] Thus, results from *Paper II* may describe associations between physical size and social acquiescence or lack of self-insight rather than the tendency to 'fake good'.[88-91]

While the personality traits included in EPQ and NEO-FFI theoretically are assumed not to correlate within the same instrument, this is not the case in the present data, which is described in Chapter IV. In *Papers I, II, III*, *and XI*, the statistical models did not include other personality traits as confounding factors. This, however, may have altered some results and also the general interpretations of each paper because of intercorrelations among some of the personality scores. Two approaches could potentially address the problem. One would be to extract the variance of each personality trait that can be explained by the other personality traits. This would imply using residuals as alternative measures of personality. Another approach would be to include the other personality traits as additional predictors in the statistical models. However, the first approach would not investigate the conventional trait scores, which would complicate the comparison with other studies, and the second approach would imply inclusion of predictors in the models that were measured all together with the outcome and mixing them with early life predictors.

Unmeasured confounding

As was the case for the papers on intelligence, several multivariate models were presented to make it possible to interpret the contribution of the different covariates. These varied in the four papers but included sex, single-mother status, parity, mother's age, father's age, mother's cigarette consumption in the third trimester, gestational age, birth weight, parity, parental SES, and age at the 1-year examination.

A possible limitation in all four papers is the likelihood of unmeasured confounding. Thus, in addition to the inclusion of other personality traits, the inclusion of proximal factors could have revealed more on the mechanisms behind the findings. The most fundamental relationships in infants and young children's lives are most often considered to be those they have together with their parents. Thus, children turn to their parents for psychological resources (including affective, behavioural, and cognitive ones), and provision of those contribute to shaping children's personality development and their competent functioning.[257] Although shared environmental influences have been found to account for very little or no variance in most personality traits of adults,[268,269] it is thus still possible that non-shared proximal influences in early life could be of importance for personality development as well as milestone development and growth measures[275,276,325] and that a lack of inclusion of such factors may have induced confounding. Finally, as with the studies on intelligence, genetic factors were not included but are, however, considered to be important predictors of personality,[326] and by extension hereof, personality characteristics of the parents were also not included in the studies.

VIII. Predictors of milestone attainment

Summary

The timing of attainment of milestones in the child's first years of life has been found to be significantly associated with a range of outcomes, including intelligence and personality, as shown in this dissertation. Various factors have been suggested to predict developmental milestones, and the dissertation contributes to the scientific literature on milestone predictors in two papers that address infant developmental milestones and milestones attained in the subsequent years, respectively.

The timing of infant developmental milestones has shown to be associated with both prenatal (e.g., gestational age and birth weight) and postnatal (e.g., growth and nutrition) factors. We conducted the first study to provide a systematic evaluation of a broad selection of predictors of infant developmental milestones; thus 19 factors within the domains of 'family background', 'pregnancy and delivery', 'postnatal influences', and 'postnatal growth' were included. A total of 18.5 per cent of the variance in the Overall mean of 1-year milestones was explained by the included factors, and variables within the domain of 'pregnancy and delivery' explained the largest proportion. Especially the factors low gestational age and low birth weight were consistently associated with later milestone attainment.

Studies on predictors of developmental milestones in the second and third years of life have especially focused on language development. In line with our study on predictors of infant developmental milestones, we conducted the first study to provide a systematic evaluation of a broad selection of predictors of milestones in this age period. The milestones were related to language, walking, eating, dressing, social interaction, and toilet training. A total of 16.2 per cent of the variance in the Overall mean of 3-year milestones was explained by the included factors, and variables within the domain of 'postnatal growth and development' explained the largest proportion, primarily because of the variable Overall mean of 1-year milestones, which supports previous findings on developmental continuity.

Additional studies on predictors of development during the first years of life are warranted with the inclusion of factors related to especially the home environment and genetics.

Background

The timing of developmental milestones during the first years of life has shown to be significantly associated with a range of outcomes from behavioural and personality characteristics[286,287,289,292] to educational and cognitive outcomes,[172,197,198,206,207] with faster development generally implying beneficial outcomes in both childhood and adulthood. A particular focus in this dissertation has been on developmental milestones, as *Papers I, IV, VII, VIII, IX, XI*, *and XII* explored how the timing of attainment of milestones is associated with intelligence and personality.

Although several studies have been conducted in the field, potential predictors of developmental milestones have typically been studied in isolation from one another, and few research efforts have incorporated multiple factors from diverse domains simultaneously. Thus, the unique and combined contributions of each factor and each domain on development related to milestones in infancy and early childhood are essentially unexplored. In *Papers V and X*, the aim was to conduct studies that incorporated multiple potential predictors into the same study. While *Paper V* focused on predictors of milestones attained in the first year of life, *Paper X* focused on predictors of milestones attained in the subsequent years.

Predictors of infant developmental milestones

In the first year of life, the emergences of a series of new motor abilities appear. Motor development can be defined as the sequence and rate at which the child acquires motor skills and thereby learns to use and control the body.[327] Although 'windows of attainment' have been put forward to provide standard age ranges for the attainment of motor developmental milestones,[102] wide age variations of attainment have been found even in healthy infants.[328,329]

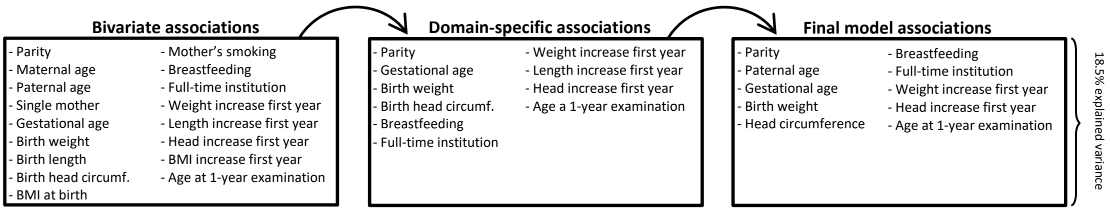
This dissertation found that development in infancy is associated with both intelligence and personality in adulthood, and younger age at attainment of motor developmental milestones have also been found to predict positive outcomes related to cognition and decreased risk of psychiatric disorders.[172,198,272,279,330] This underlines the importance of understanding potential pathways leading to the timing of infant motor development.

Empirical evidence

Studies of prenatal predictors of motor developmental milestones in the first year of life have found that especially low gestational age and low birth weight[275,331-336] are associated with later attainment, and furthermore, prenatal drinking, maternal smoking in pregnancy and maternal gestational diabetes[275,337,338] have been found to have an effect. Studies of postnatal predictors have in particular focused on growth and nutrition and concluded that, in healthy populations, motor development is largely independent of variations in physical growth[329] but significantly associated with breastfeeding.[339-341] Furthermore, siblings in the family,[342] sleep and play positioning,[343,344] and especially the timing of earlier milestones[345-347] have shown to be associated with the timing of motor development. The studies do, however, vary widely with respect to the inclusion of other possible predictors in the statistical models.

In *Paper V*, we conducted a systematic evaluation of a broad range of possible predictors of milestone attainment in the first year of life to investigate the degree to which factors related to 'family background', 'pregnancy and delivery', 'postnatal influences', and 'postnatal growth' could explain variations in infant milestone attainment. Three different methodological approaches were used; thus, results were presented for both bivariate analyses, domain-specific analyses, and a final model, in which variables with a p-value of 0.10 or below in the domain-specific analyses were included. Results for the Overall mean of milestones are illustrated below.

Figure 10. Predictors of 1-year milestones showed for three methodological approaches (modified from *Paper V*)



A total of 18.5 per cent of the variance in the Overall mean of milestones was explained by the final model that was based on findings from the four predictor domains. Variables within the domain 'pregnancy and delivery' explained the largest proportion of variance in milestone attainment compared to variables from the other domains. Additionally, milestones attained at the beginning of the first year of life were to a larger degree explained by the included predictors than milestones attained later in the first year. Thus, 17.3 per cent of the variance in milestones related to smiling and lifting the head was explained by the included predictors while 9.8 per cent of the variance in milestones related to standing and walking were explained by them.[108]

The study supports previous findings on the importance of gestational age and birth weight for development in the first year[331-336] as these factors generally had the highest estimates for all milestone means. Several of the predictors investigated in this study have not been considered in other studies of infant milestone predictors, and the study adds to the literature by giving an overview of specific factors in addition to domains that are most strongly associated with the timing of infant developmental milestones.

In conclusion, several factors are associated with the timing of infant development, and gestational age and birth weight are generally the most evidence-based predictors. Although associations are generally small for individual variables, we were able to explain 18.5 per cent of the variance in the Overall mean of milestones with predictors included in the study. However, a major part of the variance in milestone attainment is thus dependent on factors other than those included in this study and other studies so far.

Predictors of milestones in the second and third years of life

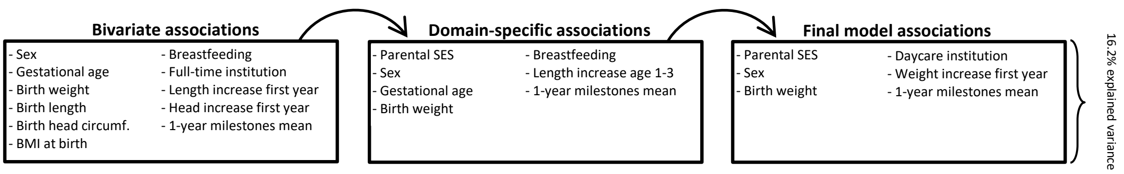
Between the ages of one to three years, children master new skills in several areas, including gross and fine motor development, language development, and social development. Research has especially evolved on language development, which in this dissertation was found to be the most important milestone category in the age period associated with intelligence and personality in adulthood. Additionally, late attainment of language has been found to be associated with negative socio-emotional, educational, and cognitive outcomes[206,207,348-351] as well as psychopathology in adulthood.[231,352] The importance of language development for later life outcomes has thus been established.

Empirical evidence

Studies concerning predictors of milestones during the second and third years of life have mainly focused on language development and found that especially parental SES[353] and maternal education[354-356] are significant predictors. Additionally, girls have been found to reach language milestones faster than boys,[354-356] and the firstborn has been found to be faster than the other siblings.[356,357] Following the findings on infant developmental milestones, low gestational age,[223,358,359] and low birthweight[360-362] have also been found to be associated with delayed language development. Among postnatal factors, the focus has especially been on stimulation where a secure attachment[363] and the communicative environment in which the child grows up,[364,365] including parents' responsiveness,[366-368] have been emphasised as important predictors of language development. A total of 7 per cent of the variance in language delay at 24 months has shown to be explained by 12 factors that included sex, gestational age, birth weight, birth order, and maternal characteristics (including language and educational aspects).[355] Moreover, studies of developmental continuity have shown that the timing of earlier motor development may be a good predictor of the attainment of later milestones related to language,[110,235,237] which is supported by the findings in *Paper VIII*. Similar to the studies on infant developmental milestones, the previous studies vary concerning the inclusion of other potential predictors in the models. Also, studies are lacking on predictors of milestones other than language that are attained in the same age period.

Corresponding to *Paper V*, *Paper X* presents a systematic evaluation of a broad range of possible predictors of milestone attainment in the second and third years of life to investigate the extent to which factors related to 'family background', 'pregnancy and delivery', 'postnatal influences', and 'postnatal growth and development' can explain variations in the timing of milestone attainment using three different methodological approaches.

Figure 11. Predictors of 3-year milestones showed for three methodological approaches (modified from *Paper X*)



A total of 16.2 per cent of the variance in Overall mean of 3-year milestones was explained by the final model. Variables within the domain 'postnatal growth and development' explained the largest proportion of variance in milestone attainment compared to variables from the other domains. The largest amount of variance explained by the final model was for the milestone mean Walking (20.3%) while the smallest amount of variance was for the milestone mean Eating (5.9%). The main predictor of milestones during the second and third years was the Overall 1-year milestone mean (only 6.3% of the variance was explained when the Overall 1-year milestone mean was not included in the model), thereby supporting previous findings on developmental continuity. Additionally, the study supports previous findings on sex differences, as girls were found to attain milestones generally faster, and supports the importance of parental SES, as high parental SES predicted faster attainment of the majority of milestones. Weight increase during the first year predicted faster attainment of all milestone means except the mean Dressing, while fetal growth and growth during the second and third years had fewer and more inconsistent associations with 3-year milestones.[369]

In conclusion, evidence suggests that especially sex, parental SES, previous developmental milestones, and the communicative environment are associated with language development. Potential predictors of other milestones attained in the second and third years have not been elucidated to a substantial degree.

Methodological considerations

Statistical methods

A framework based on three different result presentations were developed for *Papers V and X* to identify important variables from the four domains 'family background', 'pregnancy and delivery', 'postnatal influences', and 'postnatal growth (and development)'. This procedure allowed us to present possible predictors from three different angles. Thus, for an overview of the pattern of observed associations with milestone development, the bivariate analyses are applicable, while the relative importance of each factor irrespective of other factors in the same domain is applicable in the domain-specific analysis. The final models present the relative importance of each factor relative to that of all other factors selected from the domains (for factors where $p<0.10$ in the domain-specific analyses).

The obvious advantage of this framework, which was developed by Eriksen et al.,[134] is that results can be interpreted according to the context of interest. Moreover, the relative influence of each factor in addition to the explained variance of each domain of predictors and of all the factors in the final model can be estimated. Nevertheless, the method also has shortcomings; mainly, it can be criticised for potential collinearity and for the inclusion of potential mediating factors in the analyses. Thus, the method is not based on DAGS,[370] other a priori models,[364] or on stepwise regression models, but allows the included factors to 'compete' against each other in both the domain-specific and final models. A selection of variables for a final model based on previous empirical studies was not possible due to a lack of studies in this research area. However, the selection based on preliminary tests can result in inflated p-values and increase the risk of both type I and II errors, but also allows the reader to compare results from the different methodological approaches which in the longer term will allow for better comparison between studies.

Comparing the final models explaining Overall 1- and 3-year mean of milestones in *Papers V and X*, respectively, a main difference is the number of significant variables. Thus, while several variables from all four domains were significantly associated with the Overall mean of 1-year milestones, fewer were associated with the Overall mean of 3-year milestones. While especially gestational age ($\beta=-0.15$, $p<0.001$) and birth weight ($\beta=-0.16$, $p<0.001$) were significant predictors of the 1-year milestones, the two strongest predictors of 3-year milestones were sex ($\beta=-0.22$, $p<0.001$) and 1-year milestones ($\beta=0.35$, $p<0.001$). The studies did not analyse potential mediation, but effects of predictors of 1-year milestones such as gestational age and birth weight may partly be mediated through later growth and development, in particular, the Overall 1-year milestone mean wherefore these factors were infrequently significant in the final models for 3-year milestones.

Unmeasured factors

In *Papers V and X*, the inclusion of potential predictors was based on previous research in addition to data availability. We were able to explain 18.5 per cent and 16.2 per cent of the variance in the 1- and 3-year milestone means, respectively, indicating that most of the variance is explained by factors other than those included. One main area that may add substantially to the explained variance is the home environment. Thus, infant development has shown to be significantly associated with a stimulating home environment,[371] including affordances[372,373] and parental interaction,[374] and likewise, different aspects of the home environment have been found to be significantly associated with language development.[363-368] It would thus most likely have been possible to explain a larger proportion of the variance in milestone attainment in *Papers V and X* with the inclusion of specific factors related to the home environment, and also, the results in the domain-specific analyses and the final model may be biased by the absence of such factors.

The importance of genetic variance for the timing of milestone development has been determined in studies on both motor and language development,[253,254] although the extent to which they play a role is an area of debate.[277] Developmental milestones are assumed to be influenced by both maturation processes and environmental factors. Genetic disposition to early or late development may thus be important because it establishes a frame within which motor development takes place, for example, weight, body build, and maturation,[184] and furthermore, establishes a basis for language development, for example, physiological adaptions involved in speaking[375] Despite the inclusion of parental SES, which may, to some degree, account for genetic factors, an essential limitation in the two papers is, therefore, the lack of control for genetic variance, which could be done, for example by use of twin study designs.

IX. Conclusions

Intelligence and personality are considered core factors in human development over the life course. Based on a broad literature review and the results of 10 prospective studies on early predictors of intelligence and personality, in addition to two studies on milestone predictors, the dissertation contributes to the scientific literature with comprehensive evidence of possible antecedents of these individual differences.

Intelligence is one of the most researched topics within the field of differential psychology, and individual differences in IQ have been found to influence developmental trajectories across the lifespan. Historically, there has been a great interest to identify factors that influence the development of cognitive abilities, and the dissertation includes a study that compares the contribution of a broad selection of potential early predictors of IQ in adulthood. Among early predictors, we found that parental SES and sex explained the majority of the variance in adult IQ (16.2–17%). Other consistent predictors were related to physical characteristics (mainly head circumference) and behavioural characteristics (milestone development). The results, combined with those from other studies, support that the relative importance of each predictor of intelligence to a large extent depends on the methodological frame in which it is investigated. However, factors related to parental SES, including IQ, education, occupation, and income seems to be the most important when genetic variance is not taken into consideration.

While substantial motor developmental delays are often indicative of general cognitive delays, associations between motor development in the 'normal' range and cognitive outcomes are less elucidated. The dissertation includes the first two studies to address the association between a wide range of motor developmental milestones in the first year of life and IQ in adulthood. Faster attainment of several milestones, especially being able to walk without support, was associated with a higher IQ in adulthood. In one study, we also found stronger associations for infants of parents with low SES compared to those of parents with high SES. Motor development in infancy primarily showed direct associations with adult IQ and was only to a smaller extent mediated by milestones attained in the subsequent years. While previous studies support associations of infant motor development and cognitive outcomes in childhood and adolescence, the included papers establish evidence that the associations persist into adulthood.

Individual differences in the timing of language milestones have been found to be associated with a range of cognitive outcomes, especially in childhood. The dissertation includes three studies that investigate associations between 20 developmental milestones attained in the second and third years of life and IQ in adulthood. Faster attainment of language milestones was associated with a higher IQ in adulthood, and this association persisted over time until midlife. Milestones related to language and social interaction were by far the most important for IQ compared to milestones in other areas. Combined with previous studies, the findings suggest that the timing of language milestones is associated with intelligence, not only in childhood and adolescence but also in adulthood. The causal relationship between the two is, however, not uncomplicated since they, in most cases, develop in parallel.

Studies have consistently found associations between birth weight and intelligence; however, only a limited number have focused on the full birth weight range and on intelligence outcomes in adulthood. The dissertation includes the first study to investigate birth weight in relation to IQ at three different adult ages. We found that birth weight, and especially birth weight relative to gestational age, was associated with IQ at three different adult ages with IQ scores increasing across the four lowest birth weight categories up to 4 kg and declined for the highest category (>4 kg). The associations did not diminish up to midlife. Combined with previous studies, these findings support associations between birth weight and intelligence in adulthood, not only for individuals with low birth weight but in the full range of birth weights.

Personality trait scores are associated with several outcomes, including those related to health. The importance of early-life factors for adult personality traits has been proposed by several theories. With four papers, we contributed to this literature by examining three early predictors of personality in adulthood: milestone development, physical size, and parental SES.

The dissertation includes the first study to investigate associations between motor development and personality in adulthood. We found that later attainment of sitting without support, crawling, and walking with and without support were associated with increased neuroticism in adulthood. Additionally, we conducted the first study to show that the timing of language milestones was associated with personality trait scores in adulthood. Thus, faster attainment of language milestones was associated with lower neuroticism in young adulthood and with higher extraversion and openness to experience in midlife. The findings suggest that the timing of milestones in the first years of life is associated with certain personality traits in adulthood but are, however, the first of their kind wherefore further studies are needed.

Suboptimal pre- and postnatal growth is associated with adverse somatic and mental health outcomes. The dissertation includes the first prospective study to address the relationship between physical size in the first six years of life and personality scores in adulthood. We found that smaller size at birth and the following three years were associated with higher adult scores on the EPQ lie-scale in men. No significant associations were found for neuroticism, extraversion, and psychoticism and in addition, no significant associations between physical size and personality scores were found for women. The combined empirical evidence supports an association between physical size and the EPQ lie-scale; however, inconsistencies exist as to whether physical size is associated with other personality traits.

Individuals who lived in a low-status socio-economic environment early in life are more likely to experience adverse life outcomes, including health problems. We empirically investigated whether parental SES at the age of one year was associated with personality in adulthood. Higher parental SES at the age of one year was associated with lower neuroticism, higher psychoticism, and lower lie-scale score; however, these associations were all mediated by intelligence and education. The results of our study, combined with those of other studies, generally support that parents with higher SES have children who are more emotionally stable, open, and extraverted as adults, and that these may be partly or fully mediated by factors related to adult intelligence and educational level.

Finally, the dissertation contains the first two studies to address predictors of 1- and 3-year milestones, respectively, by providing systematic evaluations of a broad selection of predictors within different domains. A total of 18.5 per cent of the variance in 1-year milestones and 16.2 per cent of the variance in 3-year milestones were explained by the included predictors in the final models. For infant developmental milestones, variables from the domain of 'pregnancy and delivery' explained the largest proportion of variance, and the factors gestational age and birth weight were the most consistent predictors. For milestones obtained in the subsequent years, variables from the domain 'postnatal growth and development' explained the largest proportion of variance, primarily because of the timing of milestones in the first year of life, which was the most consistent predictor together with head circumference. Combined, the studies suggest that a major part of the explained variance in milestones attainment is dependent on factors other than those included in the studies. Studies focusing on genetic variance and proximal factors of the home environment are needed to pursue this area of research further.

In a life course perspective, the dissertation contributes to the existing research by underlining a stability of development from early to late life. It thus shows that development very early in life can have potential consequences up to 50 years later. Whether these associations are caused by direct effects of early-life factors on the development of intelligence and personality, by reverse causality of the effect of early intelligence and personality (by the parents or the child itself) on early-life development, by mutual associations or by confounding factors cannot be determined from these studies. However, the results demonstrate lifelong connections between factors in the first years of life and individual differences in intelligence and personality.

Nevertheless, it is important to acknowledge that the formation of these individual differences is not a universal, homogenous process. The findings of this dissertation thus show that many components other than milestone development, physical size and parental SES must represent points at which development can be affected with subsequent implications for cognition and personality development. Hence, several of the studies included in this dissertation were the first of their kind, which poses the question of what other studies on early predictors of intelligence and personality may be able to find in the future.

X. Perspectives

Individual differences in intelligence and personality have for decades been found to predict important life outcomes. Our findings have provided evidence that some of the individual differences in intelligence and personality may reflect individual differences in early life circumstances and early development and add significantly to the literature by pointing out specific factors that may be especially important.

From the perspective of early intervention and prevention programs, it is important to know that some early-life factors have a permanent association with intelligence and personality development. However, observational prospective studies entail many challenges, including confounding factors and differences in their effects over time, and complex mechanisms of cause and effect in a life course perspective. With only a limited number of follow-ups in the included papers, a great challenge in terms of the methodology is that both intelligence and personality develop from the beginning of life parallel to the development of those potential predictors that are being investigated. This makes it difficult to conclude on the mechanisms behind the findings. A solid understanding of these mechanisms is, however, needed before information on early life predictors of intelligence and personality can be used in designing prevention and intervention programs. From the perspective of interventions, it is thus not a trivial matter whether the associations mainly reflect a causal explanation, reverse causality, or confounding factors. If the findings are mainly due to causal explanations where early-life factors, for example, birthweight or infant developmental milestones, directly affect the development of intelligence, interventions could target fetal growth and earlier timing of milestone attainment. Conversely, if the findings mainly reflect reverse causation, such interventions will not be successful, and if the associations reflect confounding factors, interventions could be directed at the confounding factors if possible. However, in general, only relatively weak associations were found in the 10 papers on early predictors of intelligence and personality. Development is affected by numerous factors that each contribute a small part, and it is thus by focusing widely on several areas of the child's environment that one can seek to affect the development of intelligence and personality. Interventions based on the associations found in this dissertation should, therefore, be part of broader efforts to stimulate development.

Delay in motor development during the child's first year of life has recently been estimated to be present in 24.4 per cent of Danish infants.[376] Assuming a causal relationship of motor development with intelligence and personality, interventions could imply targeting an increase in the speed of motor development in the first year of life. Evidence has been provided that intervention programs have an effect on motor development in infancy; namely, programs that aim at the stimulation of the child's exploration of active motor behaviour.[377,378] Additionally, it has been estimated that 7–20 per cent of children experience difficulties with language attainment in the preschool and early school years.[355,379] In Denmark, a report from 2016 investigated 0–5-year-old children's competences and found that already, when children leave the nursery, there is more than one year difference in their vocabulary between children in the weakest group and children in the average group. When they leave kindergarten, this difference has grown up to two years.[380] Assuming causal relationships of language with intelligence and personality, interventions would imply increasing the speed of development of language. Interventions aiming at language development have shown to be effective even in general population samples, both when it targets families[381,382] and child care institutions.[383]

In addition to potentially affecting intelligence and personality development, targeting early life predictors would also affect a wide range of other positive outcomes over the life course. Thus, although the overall effects of interventions targeting potential predictors of intelligence and personality in the first years of life may cause very small population differences in these outcome measures, it may have important societal implications. Investment in early childhood has been supported by the work of James Heckman, who summarised the empirical evidence on the relative rate of return of interventions across different ages. Describing how the highest rate of return comes from investing as early as possible, between the ages of 0–3 years, the often-cited Heckman curve thus describes how the rate of return of social interventions declines rapidly with age. Based on American society, he deduced that investment in early childhood development (including cognitive skills, social abilities, and physical well-being) would change the prosperity through early skills building that will prevent inequalities in educational achievements and promote income equality.[384,385] The Heckman curve has, however, been critiqued, and recent studies do not support the conclusions.[386,387] Furthermore, generalisations to Danish contexts may be questioned, including how effective early skills building will be in Denmark compared to American society.

With this dissertation, several associations between early-life factors and intelligence and personality have now been established that were not known previously. Hopefully, future research will elucidate the mechanisms behind these findings and facilitate our understanding further on how intelligence and personality can be traced to the beginning of life. Development is determined by experiences, and environmental influences *in combination* with genetic factors and empirical testing of the mechanisms behind the findings would, therefore, imply the inclusion of both. Additionally, it would require large data sets with repeated measures of child development during the first years of life in addition to repeated measures of intelligence and personality traits in both childhood and adulthood. A great challenge in terms of the methodology is to solve the complex and continued interplay between predictors that affect one another over a life course, making it difficult to understand the full contribution of these factors with the methodology currently available.

To gain a more complete assessment of the causes and consequences of early-life development and increase the prospects of elucidating some of the potential mechanisms behind our results, infants could be followed already from conception. At a practical level, one suggestion is that fetal measurements, which are already collected at routine ultrasound scans, could be made available to researchers in the same way that birth weights are. This could be used to gain a more comprehensive assessment of the causes and consequences of prenatal development and increase the prospects of elucidating some of the potential mechanisms behind the findings in this dissertation.[388,389] Finally, the epidemiological evidence should be integrated with evidence from biological psychology and social science on the complex social and mental mechanisms underlying the development of intelligence and personality.

XI. Dansk resumé

Baggrund

Intelligens og personlighed anses for at være væsentlige aspekter ved den menneskelige udvikling og er begge associeret med en række livsudfald, som inkluderer forskellige helbredsaspekter. Der eksisterer dog kun begrænset viden om, hvordan individuelle forskelle i intelligens og personlighed opstår, hvordan de udvikler sig, og i hvor høj grad de kan tilskrives de første leveår.

Afhandlingen bidrager til den eksisterende litteratur om tidlige prædiktorer for intelligens og personlighed ved empirisk at undersøge sammenhænge mellem en række mulige prædiktorer og forskelle i intelligens og personlighed, med et særligt fokus på udviklingsmæssige milepæle i de første leveår.

Formål

Formålet med afhandlingen er at give et samlet billede af tidlige faktorer, som har betydning for intelligens og personlighed i voksenalderen. Den har specifikt til formål at undersøge sammenhænge mellem forskellige mål for intelligens og personlighedstræk målt på flere alderstrin i voksenlivet i forhold til følgende tidlige faktorer: Alder ved opnåelse af milepæle i første leveår samt i de efterfølgende to år, fødselsvægt og størrelse i de første leveår samt forældres socioøkonomiske status.

Materiale

Afhandlingen er baseret på empiriske resultater af tidlige prædiktorers betydning for intelligens og personlighed fra 12 epidemiologiske studier samt omfattende gennemgang af den videnskabelige litteratur. Studierne er baseret på Rigshospitalets mor-barn kohorte, herunder to opfølgninger af denne: The Prenatal Development Project og the Copenhagen Aging and Midlife Biobank. Derudover benyttes data på intelligens indsamlet ved sessionsundersøgelser.

Resultater

Afhandlingen slutter, at flere tidlige faktorer er associeret med intelligens i voksenalderen. Et studie af en lang række tidlige prædiktorer fandt, at forældres socioøkonomiske status, når barnet er ét år, samt køn var de primære prædiktorer for IQ; andre væsentlige faktorer var primært relateret til fysisk størrelse (især hovedomfang) og milepæle i de første leveår. Resultater fra de andre inkluderede studier viste, at hurtigere opnåelse af flere motoriske milepæle i det første leveår var associeret med øget IQ i voksenalderen. Derudover var hurtigere opnåelse af milepæle i de efterfølgende år, især milepæle relateret til sprog og social interaktion, også associeret med øget IQ. Fødselsvægt, og især fødselsvægt i forhold til gestationsalder, var associeret med IQ på tre forskellige tidspunkter i voksenlivet; intelligensniveauet steg over de fire laveste fødselsvægt kategorier og faldt ved den højeste kategori (>4 kg).

Flere faktorer var også associeret med personlighed i voksenalderen. De inkluderede studier viste således, at hurtigere motorisk udvikling og sprogudvikling var associeret med lavere neuroticisme i både ung voksenalder samt i 50-års alderen. Derudover var hurtigere sprogudvikling associeret med øget ekstroversion og åbenhed i 50-års alderen. Hos mænd var lav fødselsvægt og vægt i de efterfølgende tre år associeret med højere 'lie-scale' score men ikke med andre personlighedstræk. Højere socioøkonomisk status hos forældrene ved ét år var associeret med lavere neuroticisme, højere psykoticisme og lavere 'lie-scale' score; dog så sammenhængene ud til at være medieret af intelligens og uddannelse.

Andre studier støtter disse fund, men afhandlingen bidrager til den eksisterende forskning ved at undersøge intelligens og personlighed i voksenalderen, ved at inkludere detaljerede mål for udvikling af milepæle samt ved at være baseret på en fødselskohorte, som ikke er karakteriseret af atypisk udvikling hos børnene.

Sluttelig giver afhandlingen i to artikler overblik over prædiktorer for timing af 1- og 3-års milepæle og viser, at blandt de inkluderede faktorer kan 1-års milepæle primært forklares af gestationsalder og fødselsvægt mens 3-års milepæle primært kan forklares af milepæle i det første leveår.

Konklusioner

Afhandlingen demonstrerer sammenhænge mellem faktorer i de første leveår og individuelle forskelle i intelligens og personlighed i voksenalderen, hvilket understreger stabilitet i udvikling fra tidligt til sent i livet. Den bidrager til den eksisterende forskning ved at påpege specifikke faktorer, som især kan være væsentlige for udvikling af intelligens og personlighed.

Om sammenhængene skyldes direkte effekter af tidlige faktorer, omvendt kausalitet af effekterne af tidlig intelligens og personlighed på udvikling tidligt i livet, gensidige associationer eller konfoundere kan ikke direkte udledes af disse studier. En øget forståelse af de mekanismer, der forklarer sammenhængene, er dog nødvendig før denne viden om tidlige prædiktorer for intelligens og personlighed kan bruges til at designe forebyggelses- og interventionsprogrammer. Mens de påviste associationer ikke antages at have store konsekvenser for den enkelte, så kan de måske have substantielle implikationer i samfunds- og folkesundhedsøjemed.

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