Reading up on sex

Learning to read. Why sex matters, and whether physical fitness and activity are relevant in reading acquisition.

Master's Thesis

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Summary

When you read this thesis, you rely on a skill you acquired as a child. Most children start at the age of 5-6 years to learn single letters, write their name, and gradually develop the functional skill of decoding strings of letters; in other words, reading. By the age of 10 they are expected to read texts with concentration, endurance, fluency and coherence. The success rate varies, and Norwegian children score slightly above average when reading skills are measured globally, and are better at simple decoding, although worse at interpreting and evaluating text. Also, there is a strong trend towards girls outperforming boys at reading at this age. The demands on reading skills are growing with increasing cognitive demands put on the workforce in the Information Age. Basic skills such as reading, writing and mathematics are deemed crucial to later work life by the Norwegian Government.

So how can we further pave the way for literacy? The Norwegian Directorate for Education and Training states that "fysisk aktivitet indirekte fører til bedre prestasjoner i for eksempel matematikk og språkfag." (physical activity can indirectly lead to better performance in for instance mathematics and languages). We set out to test if boys and girls are different, and to see whether there is in fact a "spillover effect" from physical activity to reading skill in 9- and 10-year-old Norwegian children. We confirmed girls' superiority in reading. Moreover, we saw the rudimentaries of fitness effect on girls' reading skills (0.404, p=0.027), but not for boys.

Our results show that sports cannot simply be used as a means to improve academic achievement. However, because sports have health benefits, we by no means suggest that sports should be removed from the school curriculum. We would like schools to devote additional hours to training students in the technical aspects of reading, because one needs to train in the skill itself to become good at it. Given the sex differences at this age, reading training may be improved by choosing teaching methods that take into account the differences in boys' and girls' neural development. Both boys and girls will benefit from beginning with phonetic reading training, after which they should be exposed to mixed methods as their reading skills improve. Boys will suffer, however, if they do not begin to read by first starting with the phonetic method.

Introduction

In this thesis I explore the **sex differences in reading**, and assess whether physical activity and physical fitness have anything to do with reading proficiency in 9-year-old boys and girls.

The first section provides the background for **why we should be concerned** about reading skill levels in Norway. I will briefly describe what happens in the brain when we read, and then show that **reading is a skill that is learned**, and the more practice and training one puts in, the better one becomes. I will show that the brain actually uses networks for reading that were originally evolved to do something else. The **learning of reading shapes neural circuits** in the human brain through plasticity.

I will move on to show that the development of the brain follows slightly different **biologically determined routes in boys and girls**, and that differences in development also are present not only between the sexes, but also within each sex, because much of the neural underpinnings of reading readiness is genetically determined. These differences are already visible in 9-year-olds' brains, and the **differences affect the brain's reading readiness**.

Although the process of development, neural wiring and rewiring rests largely on a biological blueprint, the brain's experience also influences how it develops, and ultimately how we as individuals turn out. This is the topic of the next section.

It is well known that vigorous physical activity enhances the cardiovascular capacity of the body. Exercise is healthy, and blood nutrients and oxygen levels are influenced positively by it. I will look into **boys' and girls' physical fitness, and their physical activity level**. We often mix the two concepts in everyday speech, and consider them two sides of the same story, as they are. But the connection between the two may not be as straightforward as we might like to think. I will address up some of the lack of clarity around the association between the two, their consequences, and the gender differences in this domain.

Fitness and physical activity are both said to benefit cognitive processes, as well as our health. I will show that it may not simply be a question of vigorous activity that determines the cognitive outcome. The **brain’s different networks act almost like separate muscles**. Those that we train are the ones that become stronger, more fit. This discussion is relevant to the public discussion around how much physical activity children should have in school, where it has been stated that physical activity will improve children’s academic results, including reading. I will show that the literature in this field is very broadly founded and rarely conclusive as to the interrelation between activity, fitness and cognitive outcome.

Lastly, I will show that **for reading there is a certain amount of overlap between networks belonging to executive function**. These are used to different degrees in different kinds of physical activities, and that the **cognitive load of a physical activity** may be the most pertinent contribution to reading skill development.

Reading

"Basic skills in reading, writing and mathematics are crucial to later work life"

Perspektivmeldingen 2013

I would like to introduce the topic of reading by sharing a fact. My six-year-old daughter knows all the letters of the Greek alphabet, but they really don't make sense to her other than being signs with a sound attached to them. One of her friends from gymnastics class speaks Greek, but still can't understand how the written part of her language connects with the way she talks with her friends and family. If we were to merge these two girls' knowledge somehow, they would be able to communicate via written text, perhaps send 'old fashioned' letters to each other, communicate via text messages, and share memories.

That is what reading is about. Reading skill is both the attachment of a sound to graphemes, written signs, and the fundamental attribution of meaning to the combination of such graphemes.

We all begin our journey to literacy by coupling sound and sign: part visual, part auditory, part vocal. Then we learn to group the signs, and progress into immediate reading, coupling sense to signs. Gradually we bypass sound altogether, and form a direct route from signs to meaning.

Reading is the ability to make sense of written or printed symbols, i.e. to be able to pry out stored information from letters on screen or paper. It enables us to take part in the adventures cooked up in another person's mind, learn something new, or figure out secrets from documents. And as the world gets more connected and complicated, the need for this skill is increasing.

The demands on reading skills are growing with the increased cognitive demands put on the workforce in the Information Age. If you as a young person want to secure your chances of a good and well-paid job, then you must have very good reading skills (OECD, 2000).

In the Norwegian Government's report to the Storting called *"perspektivmeldingen 2013"*, it is clearly stated that basic skills in reading, writing and mathematics are crucial to later work life (Det Kongelige Finansdepartement, 2013). Improving reading skills in the population is thus a national political goal.

How to achieve improvement in reading skills, however, is not a straightforward matter.

Norwegian reading skills and habits

How well do Norwegians in general read? The Adult Literacy and Life skills survey (ALL) 2003 reveals that Norwegians in general read well, but still about one third of the adult population have trouble grasping the meaning of the information they are presented in written material. Younger people are slightly better at this than older people. As a country, Norway has among the best results in the world (Lagerstrøm, 2005).

The latest PIRLS results show that Norwegian children who are about 10 years old score slightly above international averages in reading. Still, a fairly small portion of the children reach the high (25%) or advanced (2%) benchmark. The average Norwegian score is 507. In comparison, other countries at the top end of the scale are Hong Kong (571 points), the Russian Federation (568 points) and Finland (568 points).

The average age of the children tested in PIRLS varies slightly, with Norwegian children tested at an average age of 9.7 years, Hong Kong children at 10.1 years old, and Finnish and Russian children at 10.8 years old on average. While the overall per cent correct on Norwegians reading tests is 51%, most of the correct answers are in basic literacy (56% correct answers), simple retrieval and straightforward inferencing (63% correct).

Norwegian children show less proficiency in complex reading tasks such as retrieving information from texts (46% correct) and interpreting, integrating and evaluating text content (39% correct) (Mullis, 2012).

A national reading assessment showed that 90% of Norwegians 15 years or older read a book in 2011. Among those who read books the average consumption was 18 books in 2011, of which four were in non-Norwegian languages. ("Leserundersøkelsen 2012 ", 2012). Norwegian reading habits are changing, and while our newspaper consumption is declining, Internet use is skyrocketing ("Norsk mediebarometer, 2011," 2012).

Reading disabilities

The importance of literacy is most evident in view of reading disabilities. The prevalence of dyslexia in Norway is about 2-5%, while the total prevalence of reading and writing difficulties is estimated at 15% (Johansen, 2001).

The consequences of reading disabilities are debilitating. It is worth mentioning the association between functional illiteracy and criminal record.
A study from the Bergen Jail found that as many as 38% of inmates had been previously assessed for reading problems, and 28% diagnosed with dyslexia prior to incarceration. While 68.4% rated their own reading skill level as above average, an assessment of reading using a Word Chain Test, “ordkjeder”, yielded an average score of 39.9 (SD 14.6) (Åge Diseth, 2009), which is approximately the mean result for 8th graders in Norway using the same test (Høien T, 1997).

Reading up

Reading is generally considered to consist of two major components: word decoding, which is the technical side of reading, and understanding of meaning in the text, the semantic part.

When children learn to read, the texts they are exposed to generally demand very little understanding, leaving the variability in early reading skill mainly up to the level of technical skill, the decoding part. As the child gets older, the texts they are offered are generally more cognitively demanding.

Learning to read Norwegian means accessing an alphabetic script that involves about 40 phonemes and 29 letters. Most phonemes are represented by graphemes consisting of one letter. It is thus a fairly easy language to read, compared to languages with more phonemes.

There are **three stages in reading acquisition** (Høien T, 1997):

Logographic: This is the pre-reading stage, where children learn the concept of attaching meaning to abstract images. At this stage the child uses the visual memory of a word, based on random visual features. An example of this is the way children believe they recognize their name in writing based on recognizing the shape of the first letter in their name as a visual feature. This stage will not be addressed to any degree in this thesis.

Phonologic: This is when readers decode words by learning the sound of each grapheme, or letter and coding them phonologically. They then connect the sounds to make words. This is the level when graphemes and phonemes are put together in a reading strategy by temporally viewing one letter after another. This strategy has many names in the literature. Some call it non-lexical, others refer to it as a strategy, or algorithm, for letter-based reading.

Orthographic: This is the instant retrieval of words from memory, based on having seen the word many times. At this stage, the recognition of words and segments is fully automated, and each familiar string of letter is perceived as a whole. Much like phonologic reading, orthographic reading is referred to in the literature by several names. Lexical reading is the most common term, and is what is used in this thesis.

Children are typically considered to move from the logographic level up through the phonologic (non-lexical) and ultimately the orthographic (lexical) level during their reading training. When a child has reached the orthographic level, cognitive resources are thought to be freed to spend on the semantic side of reading, meaning-making (Høien T, 1997).

The ways in which boys and girls access these levels, and how the lexical and non-lexical reading strategies are used differently in the two sexes, and by children of different abilities, will be covered in the upcoming sections of this thesis.

Reading is not in our genes

Writing evolved through the necessity of bookkeeping (Fischer, 2003). By as early as four thousand years ago in the Sumerian city of Ur (Uruk), about 1% of the population could write. Here, writing extended from bookkeeping to storytelling through the epic Gilgamesh, a collection of Sumeric poems about the king of Uruk and his friendship with Enkidu. The poems are packed with ethically laden situations, dilemmas and emotions. This piece of writing is generally considered to be the first book, in the traditional sense of literature (Fischer, 2003).

Humans in general have not read for more than a few generations, meaning evolution has not had time to hardwire reading into our genes. In our striving to communicate, we have found a way to transfer meaning in writing, via graphemes, using networks in the brain that already exist. We have “recycled” neural circuits, trained them to preform a task that they are capable of doing, but that they were not originally designed for. In other words, learning to read means reorganizing neural circuits in our brain (Dehaene et al., 2010).

Learning to read fluently is a process that takes its time, commonly years. This means that the neurobiological changes triggered by reading happen gradually. This means there is enough time for biological processes to take place, such as cell development, the growth and pruning of dendrites, and the proliferation and activity of neurons and cell support systems such as glial cells. In other words, the changes that reading makes to our brain result from the effect of our experience with reading, which changes the brain via plasticity, and the general development of the individual who is learning to read (Dehaene et al., 2010).

A theory of how the brain can recycle itself to become literate

The algorithms of learning, on a cellular level, are governed by intricate genetic and molecular constraints. Transforming an individual's brain circuitry so that it is capable of reading must rely on neural plasticity, which shapes neural connections through experience. By neural plasticity we mean every way the brain circuits can be transformed, such as myelination, Hebbian learning, or pruning of synapses.

Throughout human cultural history we can also see that the representation of words and symbols evolved from images (such as hieroglyphs) into simple intersecting lines. This has made deciphering in the visual system easier, as the letters look more like what the visual system was designed to process. Intersecting lines at certain angles (like letters) are optimal for processing in the primary visual cortex (Szwed et al., 2011).

As the evolution of our systems for writing, and thereby reading, have changed to fit the visual processing system, the process for the changes that take place can be called a cortico-cultural negotiation.

The Neural Darwinism of Edelman

The concept of reading and writing as a an outgrowth of a cortico-cultural negotiation, within biological and evolutionary constraints, was first introduced by Gerald Edelman in his theory of Neural Darwinism (Gerald M Edelman, 1992) and (G. M. Edelman, 1993).

Edelman argues that **selection takes place within neural networks**, strengthening circuits and synapses that have been activated, while leaving idle ones to be pruned. This is the fundamental principle that guides neural development and decline, from womb to grave.

Edelman posed this theory as a theoretical framework meant to be sufficiently broad enough to cover and connect biology and psychology. His "theory of neuronal group selection" is flexible enough to encompass the nervous system's enormous structural and functional variability, in space-time and on many levels, including cellular, molecular, anatomical, physiological and behavioural levels. The theory of neuronal group selection is a population theory, and argues that an organism's ability to categorize the unlabelled world and behave in an adaptive fashion, arises not from a set of inbuilt instructions, but rather from the process of selection on variations (G. M. Edelman, 1993).

The theory of neuronal group selection proposes three mechanisms to account for the production of adaptive behaviour by large nervous systems: developmental selection, experimental selection, and re-entrant signalling, all acting within neuronal groups. Neuronal groups are strongly interconnected, and change in synaptic strength within a group tends to enhance the adaptive response of the group as a whole.

How does this affect the development of different skills?

Skill sets are developed as a continuous negotiation between the genetic programme in a person, and the stimuli the person gets. It is a bidirectional process, and acts on a neuronal level and on an individual level. Gottlieb describes the effect of this interaction in his theory of probabilistic epigenesis where the emphasis is on the "*reciprocity of influences within and between levels of an organism's developmental manifold*" (Gottlieb, 2007).

In other words, we are not genetically predestined to become athletes or poets, nor can we become anything we want. We come with biological baggage, which can be transformed, refined and improved.

The way to learn, and thereby rearrange your cortical connections, is to work your way through four levels. If you know nothing about something, for instance before you start to learn to read, you need to begin with a general introduction to understand what the skill is (for the concept of text and what reading is, this would typically be the logographic reading level). Then you acquire and refine the skill (connecting phonemes and graphemes, and gradually learn to read fluently, the phonologic reading level). Next you automatize the skill (you no longer need to be very attentive when you read, it 'just happens automatically', like the orthographic reading level). Ultimately you reach the skill level where you are able to generalize your skill (Wiedemann, 2008).

Teaching the brain to understand written words

Seeing words is thus something we gradually teach the brain. But before the brain can be taught letter and word recognition, a series of developmental stages must be completed. Visual acuity must be developed, and speech must be learned and understood. Now, we know that an important step in learning to read is connecting phonemes and graphemes. When a child learns to connect phonemes and graphemes into words, that child has reached the single word reading level. Children usually begin to do this at the age of 5-6 years. Although they are still working on the technical acquisition of reading skills, this is an important stage. The child's ability at this stage and age to be aware of the beginnings and ends of different sounds of the language, phonemic awareness, is a solid predictor of later literacy. The child's ability to separate different phonemes at age 6 will predict how well she reads at 9 (Sprugevica & Hoien, 2003).

Neurological underpinnings of reading or learning to read as a change in neural networks

When you read, your eyes fix on letters, sending signals from the different retinal cells through the various components of the visual system, via the lateral geniculate nucleus (LGN), into the back of your head where the primary visual cortex (V1) resides. Neurons in this area respond selectively to oriented edges, length of stimuli, or direction of movement of an edge. Together these determine the basic attributes of what is seen, or as in our case, read.

From primary visual cortex, information is distributed into two separate pathways, which have been given names such as “the dual stream”, “what” and “where”, or ventral and dorsal pathway. The ventral pathway, the occipito-temporal pathway, goes from V1 to the inferior temporal lobe, and is traditionally responsible for object recognition. The dorsal stream, the occipito-parieto-temporal pathway, is known to be responsible for spatial aspects of vision and analysis of motion (Wandell, Rauschecker, & Yeatman, 2012).

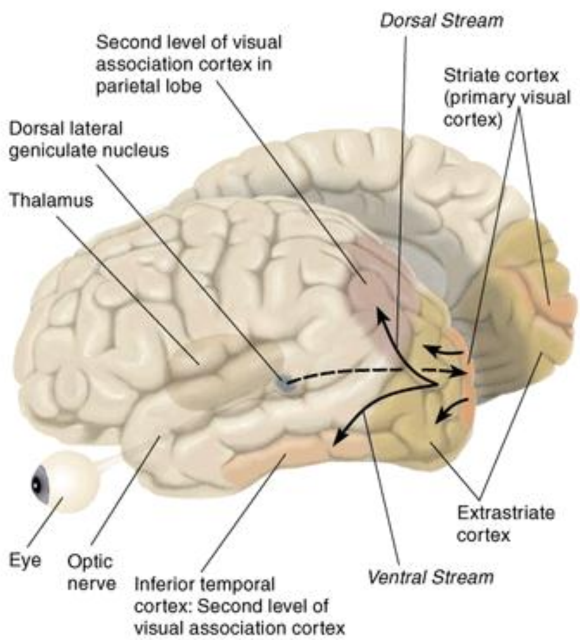

Figure 1: Schematics of the visual system. Neural signals travel from the eye through the optic nerve via LGN to the primary visual cortex. The signals are processed and sent on in different streams, dubbed the ventral and dorsal streams. Picture taken from Mark V. Albert at Northwestern University.

A review of recent neurobiological research of the cortical areas involved in reading has shown that there is a deep relationship between visual circuitry and reading (Wandell, 2011). These are the circuits that are trained to recognize written words. The area in question is the ventral occipital-temporal area (VOT), which changes its function with reading training. Damage to this area results in problems recognizing faces, forms and colours.

One part of this area has been named the Visual Word Forming Area (VWFA). This area contains the necessary circuitry to transform visual information into lexical representation (Wandell, 2011). The visual word form area was, evolutionary speaking, developed for facial recognition. Thus Dehaene suggested that reading acquisition relies on a “neuronal recycling process” (Dehaene et al., 2010). Authors believe the VWFA area in the ventral pathway is the location where we “store our words”, via neural codes.

Single word level mechanism or a neural code for words

Dehaene and colleagues propose a neural code for the written word (Dehaene, Cohen, Sigman, & Vinckier, 2005). They suggest a neurobiological scheme of progressively more complex computation as the visual signal traverses from the retina, bilaterally via the LGN, the visual cortex areas V1, V2, V4 and V8, to the left occipitotemporal sulcus (OTS).

Dehaene et al. suggest this pathway represents a hierarchy of local combination detectors (LCDs). The detectors will gradually combine contrasts and shapes into letters. These letter detectors have relatively small receptive fields. The authors further postulate that there are multiple letter detectors replicated at several locations, responding to either single or multiple letters in combination.

This yields a combinatorial code for words. Even words with missing or juxtaposed letters will be read out meaningfully, because enough neurons will be activated to invoke the pattern for the encoded combination. Evidence comes from a study by Szwed and colleagues. By using fMRI and presenting participants with either control images, mock letters and words with the same angles and junctions as actual letters, they confirmed the preferential processing of written words at multiple levels of the visual system (Szwed et al., 2011).

Visual Word Form Area

The Visual Word Form Area (VWFA)is a small area in the left lateral occipito-temporal sulcus that is of particular interest in reading skills. VWFA belongs to the ventral visual pathway. It responds strictly to visual and lexical stimulus, but not location, and is the area that evolved for face recognition. Lesions to this area cause alexia, a selective deficit in word recognition (Dehaene & Cohen, 2011).

This area changes functionality when a person becomes literate. Before a person learns to read, this area is mainly inactive when an individual listens passively to spoken words, such as speech or audiobooks. After a person has learned to read, this area responds to words presented through all sensory modalities. It is even activated in blind subjects when they read Braille (Dehaene & Cohen, 2011).

In people who can read, the VWFA responds when the person see written words. And the more literate a person is, the less VWFA responds to faces. Facial recognition is taken over by the symmetrically same area in the right hemisphere. This illustrates a prime case of neuronal recycling (Dehaene et al., 2010).

Dual Route Theory of reading

So we have an area for words we know well. And we know that a trained cortex can recognize word forms, using memory for pre-stored forms (lexical reading). But we also have a fallback algorithm, a mechanism for letter-by-letter reading to decode visual patterns that are not yet in storage, i.e. nonfamiliar words, which can be considered a non-lexical reading strategy.

We can see these mechanisms combined as a dual-process theory of learning to read: where learning to read is the process of developing both the algorithm to read letter-by-letter, and developing the means to store the resulting words (Dien, 2009).

The two processes use two “routes” that correspond partly to the ventral and dorsal pathways. Lexical memory corresponds to the ventral occipito-temporal stream, and is used to access familiar words. The dorsal occipito-parieto-frontal stream is active in non-lexical decoding, i.e. to decode words letter-by-letter (Borowsky, Esopenko, Cummine, & Sarty, 2007).

Reading comprehension is thus seen as the product of decoding skill and general language comprehension capacity.

A study of reading in 16-24-year-olds showed that decoding skill also played a part in reading in adults. Adults use lexical memory based reading more than the non-lexical strategy compared to younger readers (Braze, Tabor, Shankweiler, & Mencl, 2007).

Lexical and non-lexical decoding strategies are neurologically implemented in distinct but overlapping neuroanatomical networks (Osipowicz et al., 2011).
Non-lexical decoding is most uniquely associated with cuneus and fusiform gyrus activation, biased towards the left hemisphere. Lexical decoding is associated with right middle frontal and supramarginal, and bilateral cerebellar activation. Both decoding strategies operate in a widespread network of activation including bilateral occipital cortex and superior frontal regions (Osipowicz et al., 2011).

Borowsky and colleagues found that object identification and lexical-based reading are largely ventral and modular, showing mainly unique regions of activation. Parahippocampal and occipito-temporal gyri function are associated with object identification, and lingual, lateral occipital and posterior inferior temporal gyri functions are associated with lexical-based reading. They found very little shared activation, except in the posterior inferior frontal gyrus. Therefore the authors postulated that the two types of reading processes are primarily modular, and are perhaps a continuum of modularity and shared processing based on the type of task (Borowsky et al., 2007).

From Borowsky and Osipowicz we learn that although the two reading strategies are modular processes, they nevertheless use partly overlapping neural networks.

Perceptual aspects

Which process is used when we read a word is not only a question of whether we know the word, and have it in lexical storage. How a word is presented affects reading performance, and which areas respond in the brain. The rotation of a word makes the reading gradually more difficult with increasing angle compared to normal reading direction. Spacing of letters also increase error rate, while font size does not change performance. Difficulties arise when letters are spaced so far apart as to be perceived as single objects, not words (Vinckier et al., 2006).

When word degradation is increased and words thereby get “harder to read”, there is a gradual increased activation in the posterior VWFA, up to a threshold when the words become “unreadable” (Cohen, Dehaene, Vinckier, Jobert, & Montavont, 2008). When the reading gets tough, it takes more neural effort to read. Readers then engage in serial reading strategies, activating the posterior parietal region. This is associated with a switch from a largely automatic and parallel word identification process to an attention based reading strategy.

The authors proposed a model that incorporated a **mixture of parallel and serial processing routes** that receive differential weighting as function of input stimulus. They proposed that bilateral posterior parietal regions play an essential role whenever serial reading strategies are deployed during normal reading, or when compensatory reading is necessary due to lesions or word degradation. How unfamiliar or degraded a word is will decide which strategy is used and to what degree (Cohen et al., 2008).

Evidence from an ERP (event-related potential) study of single word reading lends support to the dual-process theory, adding temporal information to the sequence of events following a visual presentation of a word (Dien, 2009).

Upon seeing a word, a fast sequence of activations takes place, presumably cascaded, within 250ms. This happens in two phases. There is a preliminary activation to establish an initial analysis, after which there is a spread of activity across a distributed network that interacts to resolve the presented information into a coherent representation. The first phase is estimation, the second resonance (Dien, 2009). This is consistent with Edelman’s idea of re-entrant signalling in his theory of neuronal group selection.

Dien and colleagues find that after a “low level” perceptual analysis, the information is sent along the lexical or phonological pathway.
In the lexical pathway, the orthographic analysis begins. If a word is not “found” there, the information is sent on to the non-lexical decoding system where graphemes and phonemes are connected via the letter-by-letter reading algorithm.

These two pathways interact via reciprocal connections, and the result is sent on to the semantic system. The size and location of the signal origin support the dual process and dual route of reading. The ERP results place the lexical pathway along the inferior surface of the temporal lobe, strongly left lateralized. The ERP analysis showed that orthographic analysis peaks at 200ms after stimulus onset, phonological analysis at 300ms, semantic analysis at 400 ms, and syntactic analysis at 600ms.

But how do we get the words to stick in the lexical memory?
Shtyrov and colleagues found hippocampal involvement in encoding. ERP evidence showed both hippocampal and neocortical involvement in the first, immediate, memory trace formation when novel words are encoded. Entirely unfamiliar words (pseudowords) elicited activation in the left superior temporal gyrus, inferior frontal and premotor regions, and right cerebellum. A retest on the following day failed to elicit the same level of response, indicating that the response was to genuinely novel words (Shtyrov, 2012).

EEG measures show a pattern of marked decrease in N400 response amplitudes over the course of learning novel words from a sentential context, after only three exposures. A passive response in N400 to spoken words, but not for pseudowords, may be a neural signature of word-specific trace activation. Novel words matched that increase in activation, which was rapid (90-140 ms), and occurred in a passive listening situation. This may represent integration of new items into a larger context. Although this finding was for spoken words, not reading, there seems to be a cortical correlate of learning that emerges within minutes of exposure. Rapid word learning may be explained by Hebbian synaptic strengthening following correlated neural activity (Shtyrov, Nikulin, & Pulvermuller, 2010).

Training to read
The method by which you learn to read is important. Practicing that method will modulate which reading network is used, and how the brain is affected by training, as was demonstrated by Clements-Stephens and colleagues in a study of 34 adults aged 21-36 who were exposed to different training conditions. One was the phonological method, the other was learning words from a semantic context. It turns out that skilled readers will learn as much under different conditions, while less skilled, or those of average range, readers needed explicit practice with words isolated from semantic context to develop optimal neural pathways (Clements-Stephens et al., 2012).

The same neural changes that occur in a child's brain when he learns to read happen in the brain of an adult that learns to read. Dehaene and colleagues demonstrated that adult illiterates engage a broader and more bilateral ventral network in the process of learning to read than literates, and also tap into additional posterior parietal regions associated with serial effortful reading (Dehaene et al., 2010). They further showed that literacy increased the strength and specificity of the cortical response in VWFA. Literacy also led to enhanced general occipital response (Dehaene et al., 2010).

More evidence for the training effect of reading comes from Durston and colleagues. They have shown that there is an age-related shift in cortical activity during performance of a cognitive control task (Durston et al., 2006). In a longitudinal and cross-sectional study of 14 subjects at ages 9, 11 and 12, there was an enhanced activity in task critical areas, and reduced activity in less relevant areas with increased age. The authors believe that this represented a developmental shift towards **more focal cortical activation as a result of experience**. They suggested that learning happens in parallel with a change in which neural resources are activated, and that changes are made in favour of those neural areas that are critical to task performance, or the "most relevant muscles for the job" (Durston et al., 2006).

Reading as skill: influence of experience and genes

King and colleagues demonstrated with an ERP study of 21 young adults that the speed and **accuracy of processing words are related to how frequently they are used**. Words that are used daily are processed more rapidly than uncommon words, indicating that word recognition is subject to neural modulation from exposure (King

& Kutas, 1998). Furthermore, poor decoders score lower than average on all comprehension tasks, while good decoders score above average, indicating that decoding is an important skill in children. Poor readers share the same phonological issues with dyslexics. Although poor readers may not   meet the criteria for being dyslexic, they had significantly lower phonemic awareness than their normal peers.

In a longitudinal study of children aged 4-9, Hagvet (2003) found that increased language abilities correlate with increased decoding skills and IQ measures. The correlations were all moderate to high for all measures of oral and written language decoding, separating poor, average and skilled readers. Notably, phonemic awareness at 6 predicted a child's skill at reading sentences at 9 years (Hagtvet, 2003).

Individual differences

Although there is no gene for reading, genes do make a contribution to an individual's underlying ability in basic reading skills, such as phonological decoding, word recognition and reading comprehension.

Individual differences in reading comprehension are partly determined by genetic influences (Harlaar N., 2010). A behavioural genetic design was used for 436 twin pairs aged 9.86 years to determine the genetic contribution to individual differences in different aspects of reading comprehension, and how these are related to each other. Two aspects of word decoding were studied, phonological decoding and word recognition.

In a study by Harlaar (2010), word decoding was assessed by the Word Identification subtest of WRMT-R and Sight Word Efficiency (SWE) subset from Test of Word Reading Efficiency TOWRE. Specifically the genetic contribution to Woodcock Johnson Word Identification was .81 in this study, and the genetic component for TOWRE Sight Word Efficiency was .78, meaning that not much of the remaining variance could be attributed to environmental factors. The genetic component of phonemic decoding efficiency was in the same range, .73 and .71 on two measures, although the confidence intervals were fairly large.

Shared environmental influences were found for word recognition, listening comprehension, vocabulary and reading comprehension. At an etiological level, the authors found that genetic factors accounted for 52-89% of the variance in the various contributing subskills of reading comprehension, with a considerable genetic overlap between factors.

Interestingly, there was a non-shared environmental factor correlation between phonological decoding and word recognition, indicating an important role for individual specific experiences that influence word decoding. Individual specific experiences may therefore be important to the individual's learning outcome, although these factors contributed only 6-11% of the variance (Harlaar N., 2010).

A different genetic study, TEDS (Twins Early Development Study), found in a longitudinal assessment of 2-, 3-, 4- and 7-year-olds that the same set of genes that contributed to the development of language and other cognitive skills also affected normal vs. abnormal development. DNA was obtained from more than 4000 twin pairs. A strong genetic link between lexical and grammatical knowledge was found.

The authors found that language problems, even as early as age 2, are highly heritable, significantly more heritable than individual differences in the normal range of language development. They suggested a genetic basis for "g", the general cognitive ability (Trouton, Spinath, & Plomin, 2002).

In sum, we all come with **genetic baggage that influences our underlying ability** to build strong reading skills.

Sex differences in brain development

Sex differences in brain anatomy, physiology and activation may shed light on differences in language performance in children.

As the brain develops, brain tissue composition varies, and there are sex-related structural differences in grey matter and white matter development in children. Although the rough position and size of brain tissue is laid down early, myelination and pruning are dynamic during childhood and adolescence. Additionally, the brains structures and strength of connections remain subject to modification by experience (G. M. Edelman, 1993; Kleim & Jones, 2008).

Brain size is larger in males at all ages by approximately 10% in volume. The structures that are different in the sexes are the caudate nucleus, hippocampus, cerebellum and amygdala. These are all reported to have a high density of sex steroid receptors. Grey matter volume development is modulated by hormone levels and androgen receptor genotype, and follows a trajectory that peaks in size one to three years earlier in females (Giedd, Raznahan, Mills, & Lenroot, 2012).

White matter development increases more rapidly in males than females, resulting in divergent developmental paths between the sexes as they grow into adults (Giedd et al., 2012).

Wired for reading

Reading relies not just on different areas of the brain. Reading is about the communication between areas. All the signals that travel through the brain while reading run along different fibre bundles (white matter) that connect different neural reading “hot spots”. Thus, good myelination of the fibre tracts indicates good processing speed.

The signal sending ability of the white matter can be measured by Diffusion Tensor Imaging, a special version of MRI, and represented by a value of fractional anisotropy (FA). Myelination increases FA, while pruning decreases FA. FA generally is low at birth and increases with age (Wandell & Yeatman, 2013).

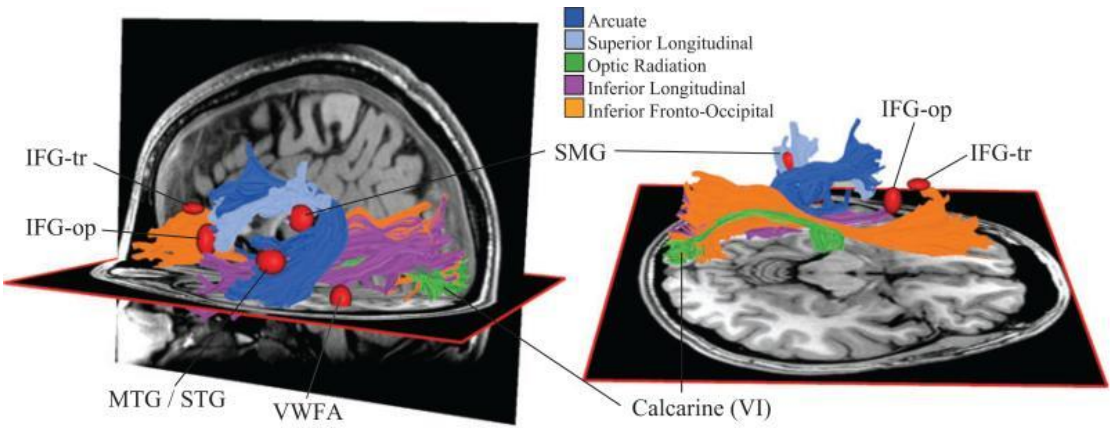

Figure 2: White matter pathways that carry essential reading signals. The two images show several major white matter fascicles in the left hemisphere from different points of view. Three of these fascicles communicate information to and from the occipital lobe. The red ellipsoids are located near cortical regions that respond (fMRI) during reading. The arcuate and superior longitudinal fasciculi include axons that terminate near these cortical regions. From (Wandell et al., 2012).

Three distinct white matter bundles are consistently found in studies of reading and the brain: the posterior corpus callossum (fibres destined for the angular gyrus), the arcuate fasciculus and the inferior longitudinal fasciculus (Wandell & Yeatman, 2013).

The pathway carrying output from the previously mentioned VWFA to the language cortex areas is in the left arcuate fasciculus, and is shown as the "blue ribbon" in Figures 2 and 3. There is empirical support for the arcuate fasciculus being an essential part of the reading circuitry, and that maturation of the arcuate is important for the development of reading related skills (Yeatman et al., 2011).

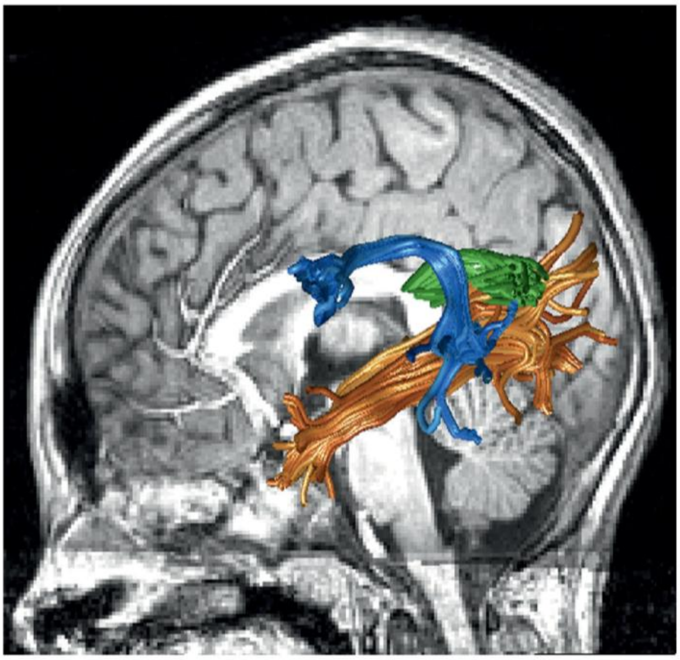

Figure 3: Reading circuitry. The arcuate fasciculus (blue), inferior longitudinal fasciculus (orange) and temporal callosal projections (green). From (Wandell & Yeatman, 2013).

The myelination of the pathway that links two of the brain's most well-known language areas, Broca's and Wernicke's, influences reading acquisition in children.

A longitudinal study of 55 children aged 7-11 years measured reading development in terms of accuracy of reading words and pseudowords, using DTI-MRI for fibre tract identification, and specific fibre groups were tracked. The study showed that radial diffusivity across the left arcuate fasciculus correlated with reading skills, especially with the accuracy of reading words and pseudowords, but not age or gender, see also Figure 4. Among measured behaviours **the left arcuate fasciculus**

was only correlated with phonological awareness, a key measure of reading readiness (Yeatman et al., 2011).

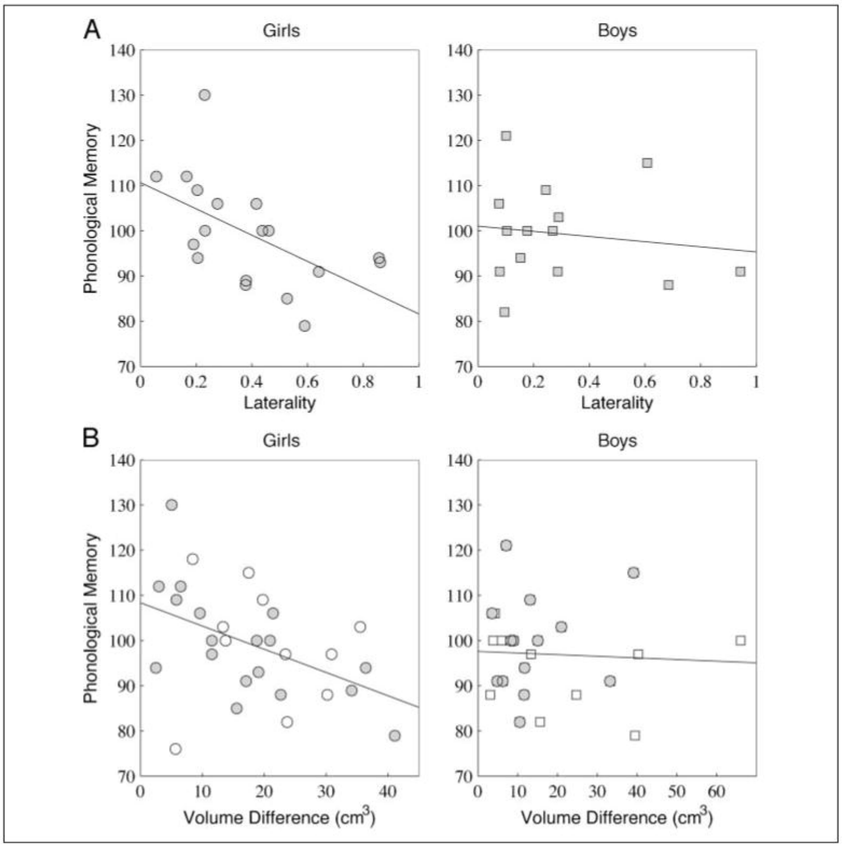

Figure 4: Relationship between age, sex, laterality and phonemic memory. Scatter plots and regression lines showing the relationship between laterality estimates and age-standardized phonological memory scores. Phonological memory is negatively correlated with laterality for girls (r -0.55, p=0.02), but not for boys (r -0.14., p=0.63). Laterality is also negatively correlated with basic reading for girls (r=-0.53, p=0.03) but not boys (r=0.34, p=0.24). From (Yeatman et al., 2011).

Dual process of white matter development

A dual-process model of white matter development has been suggested, where two processes occur simultaneously: myelination and pruning (Wandell & Yeatman, 2013). Myelination increases a single neuron's ability to transfer its action potential, i.e. diminishing the loss of the signal along the axon, and pruning weeds out superfluous neurons.

Both processes improve efficiency in communication between different areas of the brain that in turn manifests itself in reading scores. Above-average readers tend to have synchronous development of myelination and pruning while below-average readers tend to have an asynchronous development of these two developmental contributions in the signal-sending ability of the brain.

During the period from 7 to 15 years the change in fractional anisotropy (FA) is opposite for above average (increased FA) and below average (decreased FA) readers for two specific tracts, the left arcuate and the inferior longitudinal fasciculus (see also paragraph on wired for reading).

Figure 5 shows the two developmental paths as illustrated by FA measurements.

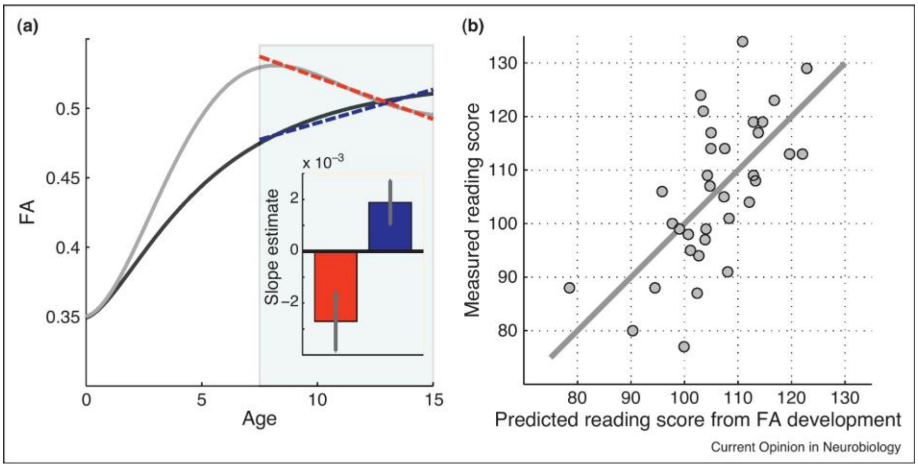

Figure 5: A dual-process model of white matter development

(a) FA development is illustrated for two cases. The two curves show the characteristics of the above-average readers (black curve – synchronous development) and below-average readers (grey curve – asynchronous development). **(b)** Combining FA development rates from the arcuate and ILF into an additive model predicts reading proficiency. From (Wandell & Yeatman, 2013)

Another DTI-MRI study confirmed the age-dependent development of myelination and its correlation with reading skills. Seventy-five Chinese pupils and students who were learning English as second language and aged 6-23 years were divided into age groups. The study revealed that different regions correlated with native language skills (Chinese) and second language skills (English). This led the researchers to postulate that neural networks underlying the two languages may be different, possibly because English is a language with letters, and Chinese a language of signs. Asymmetrical changes with an increase in white matter on the right hemisphere were found in the temporal area. This area encompasses the right inferior longitudinal fasciculus, connecting the visual cortex to the temporal pole, believed to be important for visual memory (Qiu, Tan, Zhou, & Khong, 2008). Development of functional connectivity is thus clearly related to the cognitive development, and thereby reading skill.

Dyslexia

Developmental abnormalities may manifest themselves in dysfunctions like dyslexia. Sandu et al. (2008) performed MRI morphometry on 13 dyslexic (8 boys, 5 girls) and 18 normally reading children (8 boys, 10 girls) of about 13 years old. Girls in the control group had a significantly ($p=0.039$) larger grey matter (GM) volume compared to boys, compared to the whole brain volume. The control girls also had a significantly ($p=0.021$) larger right hemisphere GM volume than the dyslexic girls.

In the dyslexia group there was no significant sex difference in GM. There was no sex difference in white matter (WM) volume for the control group, but dyslexic girls had a significantly lower WM volume. Dyslexic girls also showed significantly higher GM/WM ratio in left hemisphere than the control girls. There was a significant difference in girls when comparing dyslexic and controls, and structural differences in dyslexia can be detected at the whole brain level and hemispheres.

The study showed that the GM/WM ratio was consistently larger in girls compared to boys, indicating that girls mature faster, since this ratio increases with age (Sandu, Specht, Beneventi, Lundervold, & Hugdahl, 2008).

Volumetric sex and age differences

For more than 95% of brain structures, volumetric differences in male and female brain are uniformly scaled to the volume difference of the total brain volume in the sexes when they are in their prepubertal years (Caviness, Kennedy, Richelme, Rademacher, & Filipek, 1996). The authors performed a volumetric analysis of children’s brains aged 7-11 (mean age 9 years). This age is a critical phase for growth, where the net volumetric increment will be small, and circuitry is being fine-tuned. By this age, the brain has reached 95% of the adult volume (Caviness et al., 1996). The authors found that 98% of the brain was “sex neutral” at this age in terms of actual size.

Caviness and colleagues found that the brain areas that show sex differences were the caudate, hippocampus and pallidum, which are disproportionately larger in girls, and the amgydala, which is disproportionately smaller in girls (only 84% of male volume). Also, at this age the cerebellum has reached adult size in girls, but not in boys.

The collective subcortical grey matter structures of the forebrain of girls are already at adult volumes. These same volumes in boys are larger than in adults and must regress in volume before adulthood. Also the central cerebral white matter needs to grow in girls to a larger extent than in boys.

There is also a volumetric asymmetry in favour of the left side, which is observed in pallidum (with the left side 6% larger than right) but that is not sexually dimorphic, while a significant volumetric asymmetry for white matter that favours the right side is significant only in girls (Caviness et al., 1996).

The **final stage of brain volume increase is significantly sexually dimorphic**. There is a sex-dependent pattern of volumetric change in grey matter structures and white matter structures, a juxtaposed progressive and regressive pattern of development. Changes in the forebrain after age 11 encompass approximately 20% of net volume change in brain after this age. Boys face a projected reduction in their forebrain of 14.7 cm^3, whereas in girls this reduction is 9.5cm^3. In boys there will be increase of 75.9cm^3 in central white matter, while girls will see a 59cm^3 white matter increase during their teens - an age where sex hormones and interaction between steroids with other trophic substances such as peptide growth factors or transmitter substances takes part in what the authors call a sexually dimorphic “tonic drive” to myelination of axonal systems (Caviness et al., 1996).

Not only are there already significant size differences in some areas of boys’ and girls’ brains at the prepubertal stage, but the growth from here on will occur in a strongly sex-determined fashion.

Decoding the sex difference in reading

How different are girls and boys in reading performance?

The sex difference in phonemic awareness is significant, with girls performing better than boys both before and after an intervention with phonemic training (Moura, Mezzomo, & Cielo, 2009).

Burman and colleagues studied 62 native English-speaking children (31 girls, 31 boys) without known learning disabilities. The children were between 9 and 15 years old. The children were evaluated on two language judgement tasks in fMRI sessions: orthographic judgement (a spelling task with word pairs of similar orthography or phonology), and phonology judgement (a rhyming task). Both tasks were presented both visually and aurally.

A **sex effect was found on spelling, reading fluency, rapid naming and phonetic decoding efficiency**. The girls performed better on average on all these tasks. The most significant ($p<0.001$) sex difference was at the age of 15, on the spelling test. However, while most sex differences occurred from age 13 and up, the test of word reading efficiency (decoding pseudowords) showed that girls outperformed boys more at the age of 11 than at any other tested age (Burman, Bitan, & Booth, 2008).

The main effect of sex was on the magnitude of activation, with greater activation of brain areas that are associated with language in girls. This greater activation was generalized across tasks and age for girls. The areas that showed greater activation were the left inferior frontal gyrus and the left middle temporal /fusiform gyrus. The activation was bilaterally stronger in girls, with a weaker right hemisphere activation in boys. For boys, there was a correlation between visual word task accuracy and activation in left superior parietal cortex and precuneus. The results indicated that **boys and girls used slightly different brain areas when they were performing cognitive functions related to language** (Burman et al., 2008).

An ERP study of 28 10-year-old children (14 boys, 14 girls) showed a similar pattern of activation (Spironelli, Penolazzi, & Angrilli, 2010). The researchers identified two regions of interest from signals in the N150 and N350 areas, corresponding to the left occipito-temporal and left fronto-temporal areas. Girls showed an overall greater negativity on the right-hand side compared to boys for orthographic, phonological and semantic tasks. Boys had a general bilateral negativity. In the N350 analysis, the boys showed greater left anterior negativity, whilst girls had a more bilateral negativity during phonological processing.

Data from this ERP study suggested a neurophysiological difference in language neural networks between boys and girls. This supports the hypothesis of a gender difference in language lateralization, where girls are less lateralized to the left, relying more on the right hemisphere during language skill development than boys. The difference, however, was not seen in semantic judgement tasks, only in orthographic and phonological tasks (Spironelli et al., 2010).

An fMRI study of students aged 19-25 years confirmed the differences in lateralization, and possibly the idea that boys and girls have used their brains differently in the process of learning to read. In this study, adult native Chinese-speaking students learned words in a new language (Korean graphemes, and “fake” Korean graphemes with arbitrary meanings).

The study found sex differences in neural predictors for visual word learning. While the overall activation, as seen on fMRI, did not show sex differences in the activation in fusiform gyrus, the left lateralized fusiform activation predicted visual word reading for men but not women. Overall activation in bilateral fusiform gyrus predict to some extent post-training results for women, but not men (Chen et al., 2007).

The Word Chain Test

From the studies cited above it is evident that boys and girls acquire the technical aspect of reading, namely decoding, differently.

Development of the decoding skill can be measured by a simple screening test, the "Word Chain Test". This test maps a person's level of proficiency in the technical part of reading, but does not require a child to understand text at a meaningful, semantic level (Høien T, 1997). A more detailed description can be found in the methods section.

The Word Chain Test can be repeated as a measure of reading skill progress, and to evaluate interventions. It is a screening, not a diagnostic test. Nevertheless, a poor result on this test suggests follow-up diagnostic testing.

The Word Chain Test was standardized using 1640 children from 8 schools in Rogaland, Norway, in 1997, and has been validated against the word decoding test OS-200 (Høien T, 1997).

School year	Boys' mean score and (SD)	Girls' mean score and (SD)
3	18.7 (9.7)	17.9 (7.9)
4	21.5 (7.9)	24.3* (8.7)
5	28.1 (8.7)	27.7 (9.1)
6	33.8 (11.9)	37.2** (12.0)
7	36.7 (11.7)	41.5** (11.7)
8	38.7 (9.59)	42.1** (9.6)
9	43.7 (14.7)	46.7 (13.6)
10	50.3 (16.9)	49.3 (14.9)

Figure 6: Mean score and SD on the Word Chain Test for school boys and girls in grades 3-10

*Significant difference at .05 level. **Significant difference at .01 level. From (Høien T, 1997).

From Figure 6 we can see that boys and girls start to differ significantly in their technical reading skills by grade 4. This is the same grade and age that is examined in the present study.

To summarize:

We are born with the neural means to become literate, but there are no "genes for reading", so we have to recycle our neural networks to learn this skill. The predisposition of these networks will vary amongst individuals, and some will be less fortunate in terms of being predisposed to, or developing a disability.

We know that boys and girls develop asynchronously, and use neural resources slightly differently in their reading skill development.

In addition, the extent to which the networks are exposed to experience with reading, and the method by which one learns to read, will influence how skilled an individual reader ultimately becomes.

Physical fitness and activity

As it has been stated that increased level of physical activity may be a source of better cognitive skills (Utdanningsdirektoratet, 2011), it may be necessary to look deeper into the concepts of physical fitness (PF) and physical activity (PA).

If we are to ascertain the effect of PF and PA on cognitive outcome we first need to define and separate the concepts, and also decide how they are best measured.

In our daily language we generally use the terms fitness and activity interchangeably, without giving them much thought other than “knowing they are good for our health”. If we are to suggest PA as an academic enhancement in our schools we need to be far more precise in defining the concepts of physical activity and physical fitness.

Physical activity is defined by (Caspersen, 1985) as “*any bodily movement produced by skeletal muscles that results in energy expenditure. Physical activity in daily life can be categorized into occupational, sports, conditioning, household, or other activities. Exercise is a subset of physical activity that is planned, structured, and repetitive and has as a final or an intermediate objective the improvement or maintenance of physical fitness*.”

Caspersen also defines **physical fitness** as “*a set of attributes that are either health- or skill-related. The degree to which people have these attributes can be measured with specific tests.”*

We will refer to physical activity as any amount of activity that is reported in any way as a measure of how much a child has done, or for how long. Physical fitness is the outcome variable i.e. the measured skill performance on tests. This may be how fast a child runs, how far she throws, or cardio fitness in terms of maximum oxygen uptake.

Fitness

While fitness has been broadly defined as the “ability to perform daily tasks with vigour and alertness without undue …” (Caspersen, 1985), subsequent attempts at definitions have separated the concept further into easier-to-measure components, such as endurance, mobility and muscular strength.

Although separating fitness into single components makes it easier to measure each of them, complex movements are a combination of motor skills, mobility, coordination, endurance and strength. Physical fitness will thus be a measure of how well a child is able to perform basic movements, which for 4-12 year olds would be walking (running), jumping, throwing and climbing (Pedersen, 2006).

It is widely believed that there is a connection between physical activity, physical fitness, and motor competence. The correlation between motor competence and physical fitness has been shown to be strong in children (Haga, 2008), and that children with low motor competence have lower physical fitness than children with high motor competence (Haga, 2009).

Relating fitness and motor competence to physical activity is more difficult, because measures of activity need to take intensity into account. Pedersen (2006) mentions several studies where activity and fitness have been compared and a correlation has been found, yet he argued that the correlation in each case was low. A stronger correlation was found in studies where intensity of activity has been taken into account.

The Physical Fitness Test

Testing children for fitness is more difficult than testing adults.
Commonly, in recent literature, an assessment of fitness called the Fitnessgram, which is used by schools in the US to provide information on the status of children’s health, is used in studies of the relationship between cognitive outcome and children’s fitness (Howie, 2012). The Fitnessgram is a criterion-based rather than norm-based assessment of fitness, designed to indicate a child’s current health status. Results of each test are compared to a range of acceptable values, based on established age- and

gender-specific health standards. These standards are also changing, with slightly altered criteria, most recently in 2011 (Welk, De Saint-Maurice Maduro, Laurson, & Brown, 2011). This means that the reports shows whether a child meets or does not meet standard criteria, not whether the child is performing just above cut-off or far ahead. The child's status in terms of meeting or not meeting the criteria is used to assign them to fit or non-fit groups in studies of cognitive outcome.

The Fitnessgram contains a series of items that measure muscular strength, endurance and flexibility, as well as body composition and aerobic capacity. One challenge that the Fitnessgram faces in terms of following a child's development is that the criteria for aerobic capacity starts at age 10, making it difficult to track the development in children at a younger age (Welk et al., 2011).

To overcome these measurement difficulties, a 9-item compound motor activity test battery that is functional and easy to administer has been validated for 5-12 year olds. **The Physical Fitness Test (TPF) battery** measures combinations of endurance, strength, agility, balance and motor coordination. The test was designed to measure change in fitness over time in children, and the test battery is broadly described in (Fjortoft, Pedersen, Sigmundsson, & Vereijken, 2011) and in the methods section of this thesis.

The TPF test contains several of the same test items as the Fitnessgram, but has been designed around physical tasks that closely resemble activities children perform in their daily activities, to make the test easy to administer, and to minimize the cognitive load of the test (Fjortoft et al., 2011). For instance, in test of endurance, the TPF use a reduced Cooper test, where children run as far and fast as they can for six minutes, not 12 minutes as in the original test.

What decides fitness in children?

A Finnish study has demonstrated that achievement of cardiovascular fitness is connected to a certain amount of physical activity (Vanttinen et al. 2011). The authors traced changes in body composition, hormonal status, and physical fitness in 11-, 13-, and 15-year-old Finnish regional youth soccer players during a two-year follow-up study.

The results showed that the physical fitness of regional soccer players was better than that of the control groups in all age groups, especially in cardiovascular endurance ($p < 0.01$-0.001) and in agility ($p < 0.01$-0.001). Playing in a regional level soccer team seems to provide training adaptation that is beyond normal development and which in all likelihood leads to positive health effects over a prolonged period of time (Vanttinen, Blomqvist, Nyman, & Hakkinen, 2011).

A Norwegian two-year intervention study showed that children who take part in a minimum of 60 minutes of physical activity per day improved their cardiorespiratory fitness (CRF) significantly compared to controls who only participated in regular curriculum-defined 2x45 minutes of PA per week.

The children from the intervention school increased their mean VO_2 peak on average 3.6 mL/kg/min more than the children from the control school over the course of the two years. The intervention had its highest effect in children with low initial CRF levels (Resaland, Andersen, Mamen, & Anderssen, 2011).

Although it may seem self evident that fitness does not come without activity, exercise is not alone in influencing fitness. There are strong associations between both birth weight (Ridgway et al., 2011) and duration of breastfeeding (Labayen et al., 2012) and cardiorespiratory fitness in youth and adulthood. It is also found that depression influences cardiorespiratory fitness negatively in obese kids (Shomaker et al., 2012).

Physical activity is necessary for cardiorespiratory fitness, but the complex interactions of genetic predisposition and environmental “baggage” will account for the ultimate outcome in fitness as well as other areas.

Fitness in boys and girls

The physical differences between boys and girls need to be considered when fitness assessments are made. At the age of about 10 years, boys and girls have bodies that differ on average in all areas of fitness measures, despite the fact that they are preadolescents, and have not yet been subject to the adolescent hormones that give them more visible differences in physical appearance. When preadolescent children are assessed for aerobic fitness, strength, flexibility, speed, agility and balance, sex differences are already present (Marta, Marinho, Barbosa, Izquierdo, & Marques, 2012). The authors found that boys performed better on all items except balance and flexibility, where girls were better. Sex differences were largest in explosive strength of upper and lower limbs, muscular endurance and trunk extensor. The sex difference in motor performance was largely due to differences in levels of habitual physical activity, and body fat.

Body fat associates negatively with several motor tasks, specifically propulsion and lift movements. Boys have less body fat, and with a more lean body type they can more easily build muscle strength. Girls have a higher body fat percentage. That results in an effect of sex in all physical performance measures.

Body composition or somatotype influences fitness greatly. Somatotype, which is the relative composition of adiposity, muscle-skeletal type, robustness and skinniness in the body, stabilizes at about age 8, and is inherited to a greater degree than Body Mass Index (BMI). Somatotype interacts with pre-pubescent children's physical fitness levels, greatly influencing performance, but not equally in boys and girls. The tendency to have an endomorphic body composition, i.e. the tendency to become round and fat, influences girls' fitness negatively.

Physical activity mattered in boys, but only with a moderate effect.
Body composition mattered less in boys, but there was a positive effect of ectomorphic somatotype (tall and skinny), or mesomorphic (medium-sized) somatotype influencing fitness positively. The physical performance of boys who had an endomorphic (roundish and shorter) was not influenced by body composition.

What is puzzling is that the variables that affect girls the most seem to have little effect in boys and vice versa.

The evidence suggesting that sex and morphological typology influence fitness to a large degree may be due to some genetic determinism. Marta and colleagues argue that the presence or absence of certain physical traits determines performance level, and the amount of physical activity is less of a determinant (Marta et al., 2012).

The Fitnessgram classification of what level of aerobic capacity performance and muscular strength are within the Healthy Fitness Zone (HFZ) are separated for age and sex, but are numerically the same for boys and girls at the age of 10, before the genders are separated into different trajectories for ages above 11, where boys are expected to perform better than girls (Welk et al., 2011). The Fitnessgram classifications are said to reflect normal development and differences in boys and girls, and the different trajectories are meant to reflect the same relative fitness in boys and girls.

Thus there is a discrepancy in the literature regarding the expected fitness of 9-10 year old boys and girls. Tests conducted by Marta and colleagues suggested that boys should outperform girls on endurance and strength. But the health standards in the Fitnessgram suggest that 10-year-old girls and boys should be at same level, and that there are no measurable sex differences in fitness until about the age of 12.

There are no similar national fitness norms in Norway, only a recommendation that children be physically active 60 minutes or more per day ("Råd om fysisk aktivitet (National advice on Physical Activity)," 2013).

Physical activity

Given that children are advised to be active at least one hour per day, what is the best way to measure their activity?

Measuring physical activity

There are many ways to measure activity levels. Measurements using accelerometry, which was partly used in the Norwegian activity survey (Kolle E, 2012) is becoming more common, but still has limitations in measuring some types of postures and postural changes. The use of accelerometers eliminates some of the limitations of subjective methods (Atkin et al., 2012). Nevertheless, the subjective perception of activity, performance and feelings towards these may be of interest in a study, and might yield insights into issues such as the subject's motivational status. For this, interviews are better.

A common way of measuring activity is via self-reporting, as was done in the present study. Study subjects are asked how often and for how long they have been physically active. It is common to ask how many hours or minutes in a given period the subject has been active, for instance during the last week. Subjects are usually told to report "activity that made you sweat, or to be out of breath", or "that increased your pulse." In some instances the subject is asked to report the intensity of the exercise, which is separated into low, moderate or high intensity exercise. The self-report is usually meant to reflect a "normal week" in a subject's everyday life (Pedersen, 2006).

"Think of last week.
How many days were you so physically active that you became out of breath, or started to sweat?"

Question from study

Physical activity in Norwegian children

The physical activity of children aged 6, 9 and 15 in Norway has been thoroughly assessed in 2011 by the Norwegian Directorate of Health (Kolle E, 2012). The assessment included self-reports, measurements with accelerometers, and interviews with teachers. In broad terms the findings were that children become less active as they get older. This is what the study said on physical activity and sex differences:

Girls are less active than boys. The general level of activity has declined steadily over the years when comparisons are made with previous similar measurements of children's activity (Kolle E, 2012). Among 9-year-old girls, 69.8% are active one hour or more per day, meeting the desired minimum level of physical activity. Among boys, this number is 86.2%.

Children are **most active in the summer** (June, July, August), slightly less in spring (March, April, May) and least active in the autumn (September, October, November, December). There was no measure of winter activity in this study. There was no difference in activity between weekdays and weekend for the 9-year-olds.

As much as 56.8% of 9 year old **boys participated in team sports** (football, etc.) multiple times per week, while only 27.5% of the girls did. Endurance sports were more popular, with 60.8% of girls and 66.4% of the boys engaging in these sports once or more per week.

The feeling of fun makes boys more active. There was an association between the perception of physical activity as "fun" and the desire to engage more in sports than they do, and the actual activity level. This association was significant for all groups except the 9-year-old girls (p=0.074). The perception of "fun" in association with sports in 9-year-old boys was associated with a 10% increase in the activity level (Kolle E, 2012).

Changes in the brain after physical activity, or as result of fitness

Exercise leads to changes in the body. Some of these changes influence the brain during development. One study showed that a single bout of exercise yields a response in stimulating anabolic components of the growth hormone, and also elevates catabolic pro-inflammatory cytokines. The growth hormone influences the brain's learning and memory ability, but the cytokines started the molecular process of anti-inflammation. Thus, exercise initiates both an building-up and a destructive cycle, making it important to adjust the level of exercise so as to get the positive effect, but not overdo the activity to avoid overtraining and negative bodily responses (Nemet & Eliakim, 2010).

A different study showed an association between intensity of exercise and level of increase in Brain Derived Neurotropic Factor (BDNF) and catecholamine (dopamine and epinephrine) levels. BDNF is an important activity dependant modulator of synaptic transmission, and thus synaptic plasticity. Levels of BDNF and different catecholamines are associated with short, intermediate and long-term memory (Winter et al., 2007).

Does physical activity, or fitness measures, contribute to school results, such as reading, as the Norwegian Directorate for Education and Training (UDIR) states in the following? "Fysisk aktivitet indirekte fører til bedre prestasjoner i for eksempel matematikk og språkfag." (Physical activity can indirectly lead to better performance in for instance mathematics and languages) (Utdanningsdirektoratet, 2011).

And what is the possible underlying explanation to such a contribution if it truly exists? How do physical activity and physical fitness influence the cognitive domain?

Cognitive effects of physical fitness and physical activity

There has been a steady increase in the number of studies worldwide that assess the association between fitness, activity and some form of neural or cognitive outcome measure, be it school results, memory, executive function, or size or efficiency changes in the brain.

A recent review of 125 articles that included intervention studies of PA, fitness and cognitive effect concludes that the quality of research within this area is increasing, but the results are still inconsistent (Howie, 2012). Howie highlights a possible pitfall for this area, in that there is a political need to prove an association between Physical Activity (PA) in school and academic achievement, otherwise PA may be excluded from the school curriculum, as academic education is the school's primary job. If the academic results from PA are not shown to be present, PA will possibly lose funding. The shift became apparent in the literature around 2007 following a new US policy of "no child left behind", which led schools to cut back on PA.

The authors found an emphasis on positive outcomes, and fear that there was a publication bias that resulted in researchers not publishing null or negative results (Howie, 2012). Most of the more recent studies found either none or a positive association between some form of PA and school results. Still, according to the author, the conclusion is more often than not a weak methodology (Howie, 2012).

There is also a **plethora of types of interventions** in the studies, from short classroom breaks with stretching, to daily hours of high-intensity exercise. Many of the studies used self-reported measures of PA, and prior to 2007, all of the studies did. Most used grades or GPA (grade point average) as the academic variable. Since 2007 more researchers have started to use compound physical fitness tests batteries such as the Fitnessgram. As an overall outcome, most of the studies reported some association between PA or PF and improvement in math or reading. The review does not report sex differences in the studies. However, most of the studies were cross-sectional, making causal inferences impossible (Howie, 2012).

A review by Trudeau and colleagues showed the same level of diversity in results (Trudeau & Shephard, 2008). One Canadian study from 1970-77 showed that taking 33 minutes from math class on average to do Physical Activity yielded higher scores in math, but lower in English as second language, despite not taking time from language class. The children in the study had undergone 5 years of intervention in primary school with 5 hours of PA in school each week.

A study from California showed that children who took time from classes to do PA with a professional trainer experienced less decline in academic results than with their regular homeroom teacher or following normal PA. The first group had twice as much activity. Both the amount of PA and type of teacher may influence outcome.

Several other studies show either small or no effect of PA on academic results, with a slight trend in favour of interventions with vigorous activity, indicating a possible dose-response of interventions (Trudeau & Shephard, 2008).

A review of reviews on physical activity and mental health in children and adolescents shows some positive outcomes of physical activity on self esteem and other psychosocial factors, but also stated that:

> "*Reviews on physical activity and cognitive functioning have provided evidence that routine physical activity can be associated with improved cognitive performance and academic achievement, but these associations are usually small and inconsistent.*"
>
> (Biddle & Asare, 2011).

On the other hand, a study by Hillman et al. (2005) showed a difference in reaction time in more fit children, as estimated by Fitnessgram criteria, with faster cognitive processing speeds than less fit children, on a visual discrimination task.

The authors found a higher amplitude in the more fit children compared to less fit ones in this EEG study, and suggested this indicated that **greater attention and better working memory was associated with aerobic fitness** (Hillman, Castelli, & Buck, 2005).

Effects of physical exercise on the brain

A study of two groups of 9- and 10-year-old preadolescents, one fit, the other unfit, revealed that **physical fitness can be seen in the volume of certain parts of the brain**, as well as on cognitive control (Chaddock, Hillman, et al., 2012).

Nine- and 10-year-old children were assigned to a higher or lower fitness group based on whether their VO_2max was above or below the 70th and 30th percentiles, according to normative data. The authors wanted to determine whether more fit children exhibited superior performance on a task of cognitive control compared to less fit children. More fit children demonstrated a superior ability to flexibly allocate strategies during task conditions that required different amounts of cognitive control, relative to less fit children. The **size of the bilateral putamen and globus pallidus volumes predicted cognitive performance** for both initial and one-year-later follow-up testing. The more fit children had larger bilateral putamen and globus pallidus volumes.

The association between aerobic fitness and hippocampal volume has also been established in 9- and 10-year-olds (Chaddock et al., 2010). The more fit children showed greater bilateral hippocampal volume, and also superior relational memory task performance. VO2 max was positively correlated with relational memory accuracy (r = 0.287, p = 0.05), VO2 max was positively correlated with bilateral hippocampal volume (r = 0.351, p = 0.01), and bilateral hippocampal volume was positively correlated with relational memory accuracy (r = 0.333, p = 0.02).

While the more fit children outperformed the less fit children on the relational memory task, the groups performed equally on an item memory task. The authors believe hippocampal volume mediates the relationship between fitness level and hippocampal relational memory. The hippocampal volume difference in the two fitness groups was bilateral, and the fitness effect did not differ between the hemispheres. Chaddock and colleagues proposed a theory of hippocampal mediation to explain the fitness effect on relational memory (Chaddock et al., 2010).

The positive effect of fitness on hippocampal plasticity and memory was confirmed by Monti and colleagues in an eye-tracking randomized intervention in 51 children of 9.4 years of age (Monti, Hillman, & Cohen, 2012). The fitness effect on relational memory was clear, and the effect on item memory was not present.

A randomized control physical activity intervention study in 7- and 9-year-olds showed that **the greater the cognitive load on a task, the greater the effect of fitness**.

The intervention lasted for 150 days of a 170-day school year, and consisted of 40-minute fitness stations, then a nutritional snack, then engagement in low organizational games centred around a skill theme (i.e. dribbling). The skills section tasks were aerobically demanding. Aimed at improving working memory, the intervention led to both increased cardio fitness, and cognitive results on a modified Sternberg task. EEG analysis showed a selective effect for certain amplitudes, suggesting that changes in cognitive strategy may underlie more effective cognitive control in the intervention group.

The authors suggested that cognitive control operates along two distinct strategies, one proactive and one reactive. The proactive strategy is oriented towards future selection, and shows sustained or preparatory lateral Prefrontal (PFC) activation prior to the imperative stimulus. This strategy was supposed to result in sustained active maintenance of task goals in the child's brain. They believed the changed task EEG profile in the intervention group reflected a shift in cognitive strategy towards a more effective working memory network (Kamijo et al., 2011).

Does PA have the same cognitive effect on boys and girls?

A study of 254 743 student TAKS records (standardized academic test) and Fitnessgram results from 13 Texas schools revealed that the fitness effect on academic achievement varied with age and gender for children in grades 3-11 (Van Dusen, Kelder, Kohl, Ranjit, & Perry, 2011). The authors found an overall positive correlation between fitness, cardio fitness the most, and academic results. They found a peak effect in late middle to early high school, the age when children have entered adolescence.

The correlation was higher for cardio fitness and math (.34 in boys, .33 in girls) than reading, where the correlation between cardio fitness and reading was present to a larger extent in girls (.27) than in boys (.17). The point estimates for the association had a positive outcome for all grade-test-gender combinations, except fourth and sixth grade for boys, where the association was negative, albeit small, see

Figure 7. While the girls showed a positive linear association between cardio fitness and reading, the association was neither strongly present nor linear in boys compared to girls (Van Dusen et al., 2011).

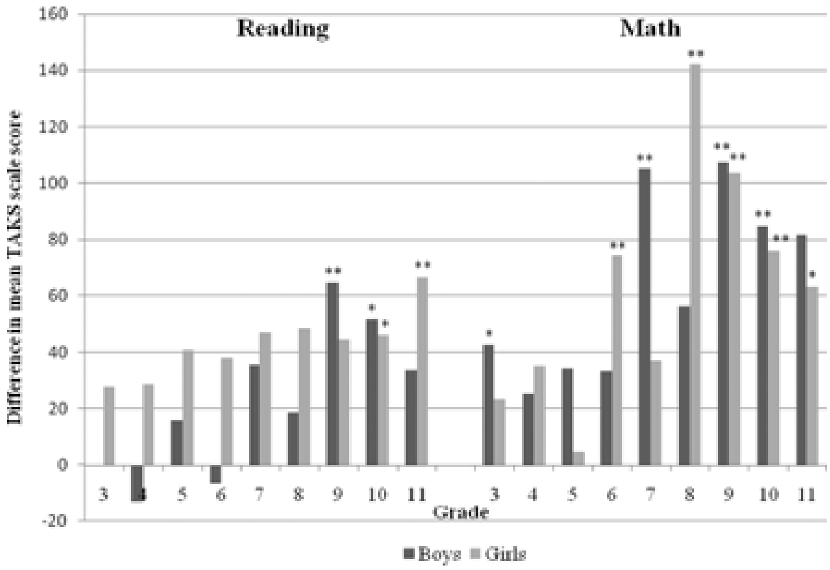

Figure 7: Association between aerobic fitness, and reading and math score on TAKS assessment for boys and girls.

Mean TAKS score in reading and math, correlation with fitness in boys and girls, in different grades. * Significant difference at .05 level. ** Significant difference at .01 level, From (Van Dusen et al., 2011).

The higher fitness association for math than reading was confirmed in a study of 5th, 7th, and 9th graders in California, with the mile run a significant predictor of CAT scores on math. The authors also observed a weak linear trend for fitness-reading association (Roberts, Freed, & McCarthy, 2010).

Another longitudinal study followed two cohorts of students from 4th to 7th grade (1325 students) and from 6th to 9th grade (1410 students) to examine the ways that student physical fitness and changes in fitness aligned with school performance in the years from 4th to 6th to 9th grade (London & Castrechini, 2011).

The authors found that a lower socioeconomic status (SES) was correlated with lower fitness. They also found that more girls in the younger grades had a high score on CST, the California Standardized Tests. The authors tracked the gap in performance trajectories and concluded that academic disparities in English and math begin before students are tested for physical fitness, that is before 4th grade. They found a change in academic results that corresponded to change in fitness, but no evidence that fitness was the determinant factor in the development of academic results. The initial gap was the stronger predictor of academic results (London & Castrechini, 2011).

A nine-year intervention study with daily physical exercise of 45 minutes found a positive outcome on motor skills and school performance. The sum of marks in academics (Swedish, math, English and also PA) was significantly larger in boys in the intervention group. Among girls the control group had higher sum academic scores (Ericsson & Karlsson, 2012).

A 16-month clustered randomized trial in 10 schools, (8 intervention, 2 control) added on average 47 minutes per week of physical activity for 143 boys and144 girls in grades 4 and 5. The interventions included diverse in-school activities, with a minimum additional 15 minutes per day of skipping rope, general movement, and chair aerobics. This intervention did not affect academic performance, measured on Canadian Achievement test (CAT-3), in a negative way, the authors report (Ahamed et al., 2007).

Activity, fitness and the executive function hypothesis

A review of the literature on physical activity, physical fitness and the association with academic performance reveals differing results, great variability in intervention design and measurement methods, and a lack of clear causality. But the presence of positive results cannot be ignored.

Tomporowski et al. have suggested that the **common denominator for fitness, activity and cognitive outcome are the executive functions** (Tomporowski, Davis, Miller, & Naglieri, 2008).

Executive functions are involved in planning and selecting strategies that organize goal-directed actions. These processes are different from the basic information processes such as primary visual processing. The executive functions are combined efforts of underlying elemental processes such as Set-shifting (focus on relevant task), Updating (monitoring mental representation, working memory) and Inhibition (deliberately suppressing prepotent response). The authors evaluated the literature on the effects of exercise on cognitive performance (this included intellectual function, cognitive abilities and academic achievement), in view of the executive functions hypothesis.

They found that aerobic exercise in general had a moderate effect on overall cognitive performance. The greatest effect was found on executive functioning, the least on cognitive speed. They also found that **the more compound the test, the higher the effect of exercise on cognitive performance**, i.e. the more complex the stimulus environment, with constantly changing elements, the more demanding was the task for executive function.

Children who were physically fit performed complex cognitive tasks more rapidly and displayed patterns of activity in the brain that indicated that fit children used their brain resources more efficiently (Tomporowski, Davis, Miller, et al., 2008). Another study by this group tested the effect of an aerobically challenging, but cognitively undemanding task, treadmill running, on a group of overweight children. Here they showed that the treadmill exercise had no effect on the cognitive results on task-shifting, a core component of executive function (Tomporowski, Davis, Lambourne, Gregoski, & Tkacz, 2008).

Physiologically, aerobic exercise engages executive and other higher-order cognitive processes by requiring goal-directed behaviour and coordination of motor movements. This means a co-activation of both the prefrontal cortex and cerebellum. For instance, if you play basketball, you need to anticipate the movements and choices of your teammates, and the players on the other team. In addition you have to pay close attention to the constant changes of all participants' positions, and plan your own moves.

This places a high demand on your cognitive resources, in addition to the demands on the cardiovascular system. **Physical exercise may be a way of exercising components of other skills in a complex, almost randomly presented fashion**. Less rapid than regular skill acquisition, but still a skill acquisition (Best, 2010).

Furthermore, chronic exercise has shown an upregulation of several growth factors, including IGF-1, vascular endothelial growth factor VEGF, and brain-derived neurotrophic factor BDNF. As described previously, BDNF plays an important role in activity dependant modulation of synaptic transmission, and thus synaptic plasticity. It should be noted that the neural circuitry in the prefrontal cortex is critical to executive functions, and matures late in adolescence and young adulthood (Veroude, Jolles, Croiset, & Krabbendam, 2013).

Purpose and aim

The literature does not clarify the association between the technical acquisition of word decoding skills, and the level of physical activity or physical fitness measures in preadolescents. Nor do we know to what degree sex influences this association.

In this study we aim to establish if there is a sex difference in word decoding, physical activity level, and physical fitness performance in 9-year-old boys and girls in Norway.

We further wish to see if there is an association between word decoding, physical fitness and physical activity level in 9-years-olds, by measuring the association between:

1) Physical Fitness and Word Decoding (PF vs WD)
2) Physical Activity and Word Decoding (PA vs WD)
3) Physical Activity and Physical Fitness (PA vs PF)

We also ask if there is a sex difference in the associations between:

a) Physical Fitness and Word Decoding (PF vs WD)
b) Physical Activity and Word Decoding (PA vs WD)
c) Physical Activity and Physical Fitness (PA vs PF)

We propose to test the level of physical fitness in 9-year-olds in Norway with a 9-item test battery of compound physical fitness activity that recruits various combinations of endurance, strength, agility, balance and motor coordination (Fjortoft, Pedersen, Sigmundsson & Vereijken, 2011). To sample reading skill we will use the Word Chain Test (Høien, Tønnesen, 1997). The subjects will also report their own level of physical activity on a questionnaire.

Questions and hypotheses

Based on the present literature we expect a difference in reading skill level in favour of girls.

We expect boys and girls to perform at about the same level on physical fitness, except for balance and flexibility, where girls are expected to perform better.

We furthermore expect a difference in activity level, with boys being more active than girls.

We expect a small but real effect of fitness on reading scores, more so in girls than boys, and we expect no influence of activity level on reading scores for either sex.

Furthermore, we expect that the girls' levels of activity will influence their fitness scores very little, but at the same time we expect that the boys' level of activity will be associated with their fitness scores.

We asked children aged 9 years:
Are girls better readers than boys?
Are boys more physically fit than girls?
Are boys more physically active than girls?
Are children who are more physically active, or more physically fit, better at reading?
Is there an association between the level of activity in preadolescent children and their physical fitness? Is there a difference in boys and girls with regards to this association?

Methodology/statistics

Participants

Sixty-seven school children aged between 9 and 10 years, all attending year 4 in a Norwegian school in the city of Trondheim, completed the Word Chain Test (WCT), the Test of Physical Fitness (TPF) as well as answering a questionnaire about their physical activity the week before. Their mean age was 9.7 years (SD=0.3). The sample includes 36 boys (mean age 9.6, SD 0.3) and 31 girls (mean age 9.7, SD 0.3). Participants and parents were given written information beforehand about the nature of the study, and written consent was obtained from parents/guardians. ID-markers were used to maintain anonymity in the data set. No child had a reported history of any learning difficulties or behavioural, orthopaedic or neurological challenges that would warrant exclusion from the study.

The Word Chain Test

All children completed the Word Chain Test. The results are presented in Table R1. The test takes four minutes to complete after the task has been thoroughly demonstrated. Children receive a sheet of paper with chains of words where each chain consists of four words.
The length of each word varies from 2 to 7 letters. All word classes – verbs, nouns, adverbs and so on are represented in the word chains. The child is instructed to mark with a line where there should have been a space between the words. The child is also instructed to make as many marks as possible within the four-minute timeframe. Every word chain must be marked with three vertical pencil marks, one for each missing space. The test contains 90 word chains. The child gets one point for each correct score, three correctly placed vertical marks in one word chain. An example of how a child should mark spacing between words in word chains is shown in Figure 8.

Figure 8: Word chains in Norwegian, with red arrow markings to illustrate how a child is expected to separate the words.

The Physical Fitness Test (TPF)

The TPF is a measure of physical fitness that aims to give a reliable quantification for children aged 5-12 years, based on everyday activities, to minimize cognitive load of tasks. The test consists of 9 test items, 3 based on jumping, 2 based on throwing, 1 based on climbing and 3 based on running. Apart from the "climbing wall bars" test item, most tasks are found in similar test batteries such as the Fitnessgram, which is widely used in studies of children's fitness.

Scores for all children, girls and boys, on all 9 items are given in Table R1, along with a computed sum score for total fitness. The items are listed in detail below.

TPF 9 test items:

Standing broad jump.

The child starts with the feet parallel, one shoulder width apart. At the signal, the child jumps forward as far as possible. The child gets two attempts, and the better one is scored.

Jumping 7 m on two feet

The child jumps with both feet together as quickly as possible. The test item score is the better of two attempts, scored in seconds.

Jumping 7 m on one foot

The child jumps 7 metres as quickly as possible on one foot. The child chooses which foot. The better of two attempts is scored, and time is measured in seconds.

Throwing tennis ball

The child throws a tennis ball as far as possible with one hand. The child chooses which hand. The contralateral foot is positioned in front of the ipsilateral foot. The better score of two attempts is scored, in centimetres.

Pushing 1 kg medicine ball

The child stands with feet parallel and shoulder width apart, ball held to the chest with both hands. The child pushes/throws the ball forward. The length, better of two attempts, is scored in centimetres.

Climbing wall bars

The child climbs a wall bar (255cm high, 75 cm wide) then crosses over two bars, and climbs down the fourth bar, as quickly as possible. The child gets two attempts. Time needed to complete the climbing is scored in seconds.

Shuttle sprint

The child runs 5 metres 10 times as quickly as possible. Time in seconds is scored. The child gets one attempt. If a procedural error is made, the test is repeated.

20 metre sprint

The child sprints 20 metres from a standing position. The time needed to complete is scored in seconds. If a procedural error is made, the test is repeated.

Reduced Cooper test

The child runs (or walks) around a rectangular field measuring 9x18 metres (this is the size of a volleyball field). The child runs or walks non-stop for 6 minutes. The score is the number of metres covered in 6 minutes.

The TPF assessment took place in the school gymnasium during school hours. The children wore suitable clothing for physical activity. The testing was performed individually by test protocol trained assistants. Throughout the testing, the children were given verbal support and encouragement. When a child made a procedural error the instructions were repeated, and demonstrations of the task made before the child made a new attempt.

The questions

Children were asked to recall their last week and answer the following questions:

1) Think of last week. How many days were you so physically active that you were out of breath or broke a sweat?
   Possible answers were: 0 (none), 1 day, 2-3 days, 4-5 days, 6-7 days.

2) Think of your most physically active day last week. How many hours were you active on that day?
   Possible answers were: not active, less than 1, 1-2 hours, 2-3 hours, more than 3 hours

Data reduction and analysis

SPSS (version 20.0) was used for statistical analysis. Correlations were calculated with either Pearson or Spearmans rho as appropriate, and a T-test was used to compare means in boys and girls to determine the sex difference in scores. We also ran a linear regression. In order to express the subject's total performance on the Physical Fitness Test as one score, a total score for the test was calculated by transforming the test item scores into a standardized score (z-scores) from the mean of the whole sample (n = 67).

Results/findings

All 67 children completed the tests. The means and standard deviations for age, measures of Test of Physical Fitness, scores on the Word Chain Test and scores on self-reported physical activity for the whole sample and for the girls and boys are shown in Table R1.

Table R1. Descriptive statistics of age, physical fitness, word chain score, and self-reported activity level.

Variable	Whole group		**Girls**		**Boys**		P-value[#]
N =67, 31 Girls, 36 Boys	Mean	SD	Mean	SD	Mean	SD	
Age	9.69	.28	9.75	.28	9.65	.27	
Subcategories TPF							
Standing broad jump	1.34	.20	1.32	.19	1.37	.21	.348
Jumping on two feet 7 m	3.83	.99	3.53	.60	4.08	1.18	.022*
Jumping on one foot 7 m	2.95	.48	2.92	.52	2.98	.45	.577
Throwing a tennis ball	14.16	2.98	12.99	2.82	15.17	2.77	.002**
Pushing a medicine ball	4.33	.68	4.24	.60	4.41	.74	.339
Climbing wall bars	6.52	1.73	6.54	1.80	6.49	1.70	.913
Shuttle sprint, 10x5m	23.22	2.61	23.08	2.55	23.34	2.68	.684
20 m sprint	4.45	.37	4.40	.40	4.49	.35	.350
Reduced Cooper test	948.21	138.65	937.61	123.00	957.33	151.98	.566
Total Score Computed for TPF	0.00	5.99	-0.11	5.84	0.61	6.18	.635
Perceived physical activity per week							
Days[a]	3.01	1.13	2.97	1.02	3.06	1.24	.744
Hours[a]	3.12	.93	3.03	.91	3.19	.95	.481
Word Chain Test	21.88	7.37	24.45	6.57	19.67	7.38	.007**

Descriptive statistics of age, physical fitness (Test of Physical Fitness, TPF), score on the Word Chain Test, and score on self-reported physical activity for the whole sample (N=67), boys (N=36) and girls (N=31).
#P-value for difference between boys' and girls' scores. * Correlation is significant at the 0.05 level *($p<0.05$)* ** Correlation is significant at the 0.01 level *($p<0.01$)*
[a]Number of days and hours of physical activity was recoded into measurable categories when analysing data. Categories used for each response were: 0,1,2,3,4, indicating as follows: never, once a week, 23 days, 4-5 days, 6-7 days per week; and never, less than one hour, 1-2 hours, 2-5 hours, more than 5 hours on most active day.

The results from the Word Chain Test show that the average score was 21.88 (SD 7.4) correct markings on the word chains. The norm value for 4th grade was 22.8 (SD 8.4) ((Høien T, 1997). Girls performed significantly better than boys (p=.007), and to norm scale, with a mean score of 24.5 (SD 6.6) while boys scored a mean of 19.7 (SD 7.4), slightly underperforming compared to the norm (Høien T, 1997).

There is no overall difference in girls' and boys' performance on the fitness test. For each of the nine subcategories, there was a significant difference in only two. In the jump 7 metres on two feet task, girls were faster than boys, p=.022.
In contrast, boys threw a tennis ball significantly (p= .002) farther (15.17 m, SD 2.77) than girls (12.99m, SD 2.82). Boys performed significantly better than girls on two subcategories of the physical fitness test: jumping on two feet (p=.022) and throwing a tennis ball (p=.002).

The results show that most children were active, and that there was no significant sex difference in the number of days active per week (girls 2.97 days, SD 1.02, boys 3.06 days, SD 1.24, p=.744). Nor was there a difference in number of active hours on the most active day (girls 3.03, boys 3.19, p= .481).

Relationships

Correlations between TPF, WCT and self-reported physical activity for the whole sample are presented in Table 2, for the girls in Table 3, and for the boys in Table 4. Since the physical activity measures were not normally distributed (Kolmogorov-Smirnov Z = 1.362, p=0.049 for days and Z = 2.068, p<0.0001 for hours) we used Spearmans rho to correlate the TPF and Word Chain Test with the self-reported physical activity, but Pearson's rho for TPF and WCT.

Table 2: Correlations between total score on TPF, Word Chain Test, and self-reported activity for the whole sample

			Perceived physical activity per week	
	TPF	WCT	Days[a]	Hours[a]
TPF	1	.064	.206	.237
WCT		1	.063	-.077
Days[a]			1	.609**
Hours[a]				1

Correlation (Pearson's, 2-tailed) between total score for Test of Physical Fitness (TPF) and Word Chain Test and Spearmans' rho for correlations with self-reported physical activity for the whole sample (N=67)
* Correlation is significant at the 0.05 level *(p<0.05)* ** Correlation is significant at the 0.01 level *(p<0.01)* [a]Numbers of days and hours of physical activity was recoded into measurable categories when analysing data. The categories used for each response were: 0, 1, 2, 3, 4, indicating as follows: never, once a week, 2-3, 4-5, 6-7 days a week and never, less than 1 hour, 1-2, 2-5, more than 5 hours on most active day.

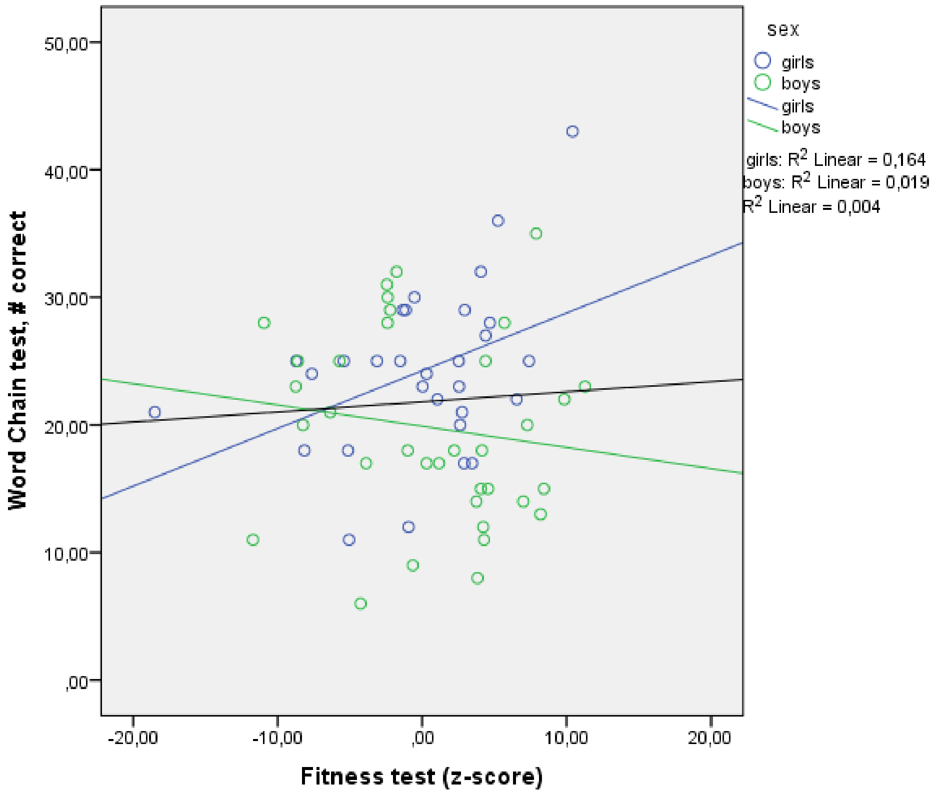

Figure 9: Scatterplot for the relationship between Word Chain Test and Fitness. Blue circles denote girls and green circles denote boys. The lines are linear regression lines, black for the whole sample, blue for girls and green for boys.

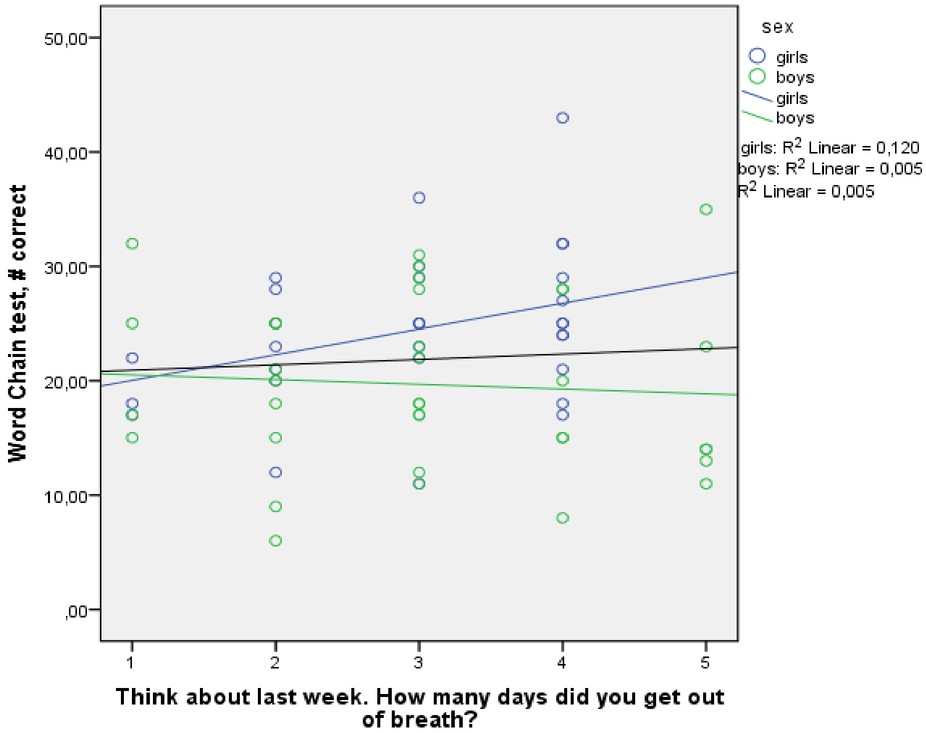

Figure 10: Scatterplot of the relation between physical activity (self-report) and Word Chain Test performance. Blue circles are data from girls, green circles are data from boys. Regression lines by sex and for the whole sample (black line).

Whole sample (N= 67)

There was a low correlation (.064) between the total score on the Physical Fitness Test and the Word Chain Test for the whole sample. A low correlation was also found between the Physical Fitness Test and the self-reported measures of physical activity (Days= .206, Hours= .237). There was also a low correlation between the Word Chain test and the self-reported measures of physical activity (Days= .063 and Hours=-.077) (see Table 2).

Girls (N=31)

Results of correlations between the Word Chain Test score, fitness score and perceived activity for girls are reported in Table 3.

Table 3: Correlations between total score on TPF, Word Chain Test, and self-reported activity for the girls.

	TPF	WCT	Perceived physical activity per week Days[a]	Hours[a]
TPF	1	.404*	.004	0.148
WCT		1	.329	0.118
Days[a]			1	.637**
Hours[a]				1

Correlation (Pearson's, 2-tailed) between total score for Test of Physical Fitness (TPF) and Word Chain Test and Spearman's rho for correlations with self-reported physical activity for the girls. Correlation is significant at the 0.05 level *(p<0.05)* ** Correlation is significant at the 0.01 level *(p<0.01)* [a]Numbers of days and hours of physical activity was recoded into measurable categories when analysing data. The categories used for each response were: 0, 1, 2, 3, 4, indicating as follows: never, once a week, 2-3, 4-5, 6-7 days a week and never, less than 1 hour, 1-2, 2-5, more than 5 hours on most active day.

There was a relatively high and significant correlation (0.404) between the total score on the Physical Fitness Test and Word Chain Test for the girls. There was also a low correlation between the Physical Fitness Test and the self-reported measures of physical activity (Days=.004, Hours=0.148). A moderate correlation (p=0.071) was found between the Word Chain Test and the self-reported measures of physical activity, more so on number of active days per week (Days= .329) than on hours per day (rho=.118).

Boys (N=36)

Results of correlations between the Word Chain Test score, fitness score and perceived activity for boys are reported in Table 4.

Table 4: Correlations between total score on TPF, Word Chain Test, and self-reported activity for the boys.

			Perceived physical activity per week	
	TPF	WCT	Days[a]	Hours[a]
TPF	1	-.138	.304	.299
WCT		1	-.115	-.163
Days[a]			1	.604**
Hours[a]				1

Correlation (Pearson's, 2-tailed) between total score for the Test of Physical Fitness (TPF) and the Word Chain Test and Spearman's rho for correlations with self-reported physical activity for the boys (N=36)** Correlation is significant at the 0.01 level *($p<0.01$)* [a]Numbers of days and hours of physical activity was recoded into measurable categories when analysing data. The categories used for each response were: 0, 1, 2, 3, 4, indicating as follows: never, once a week, 2-3, 4-5, 6-7 days a week and never, less than 1 hour, 1-2, 2-5, more than 5 hours on most active day.

There was a low correlation (-.138) between the total score on the Physical Fitness Test and Word Chain Test for the boys. There was also a relatively moderate correlation between the Physical Fitness Test and the self-reported measures of physical activity i.e. rho (Days)=.304, p=.076; rho (Hours)=.185, p=.081). A low correlation was found between the Word Chain Test and the self-reported measures of physical activity: rho (Days)= -.115 and rho (Hours)=-.163).

To gain a better picture, we ran a regression where the dependent variable was the number of correct items in the Word Chain Test and with the physical activity, fitness and sex entered as predictors. The regression yielded an effect of sex on the Word Chain Test (t=-2.735, p=.008) but no effect of fitness or activity. When running the regression separately for each sex, we found no significant contribution of fitness or PA in boys on the Word Chain Test. However, in girls the performance on the Word Chain Test was significantly influenced by fitness (B= -0.027, t=-2.927, p=.007) and days of physical activity (B=3.064, t=2.375, p=.025). Thus, the more girls were active during the week and the better they scored on the fitness tasks, the more correct word chains they had.

Discussion

The main purpose of this study was to examine sex differences in reading performance, activity level and physical fitness in 9-year-olds in Norway, and to look into possible sex differences in the associations between reading, physical fitness and physical activity.

Reading

We confirmed girls' superiority in reading. The Word Chain Test is reliable in terms of measuring the technical decoding skills of children at this age (Høien T, 1997) and girls performed to norm, significantly better than the boys. The boys scored less than the norm.

There are several factors that may contribute to the explanation of this.

The area of the brain that is used in reading matures earlier in girls than in boys. We have established the biological difference between boys and girls. We know from the literature that the neural networks underlying reading ability differ in their development in boys and girls (Spironelli et al., 2010; Wandell & Yeatman, 2013; Yeatman et al., 2011) and that there is a strong genetic component to this (Harlaar N., 2010; Trouton et al., 2002). As girls tend to have earlier maturation of the neural networks used in reading (Caviness et al., 1996; Dien, 2009) they may capitalize on this effect and read more because they master reading earlier than boys.

And they do; **girls read more than boys**. A survey of children's media use showed that girls on average read more magazines and books than boys, and that their use of social media is more directed more towards chatting than boys ("Barn og medier 2012– Fakta om barn og unges (9-16 år) bruk og opplevelser av medier," 2012). This means that girls are exposed to more text than boys, and that they write more, giving them a training effect outside of school (where they presumably have a comparable amount of reading and writing in school, since they are in the same classes as boys, and have the same curriculum). Knowing the neural networks are refined and strengthened by experience and gradually become more focal in their activation (Durston et al., 2006), the sex gap will remain wide unless the amount of reading is increased in boys.

There are several factors that influence **the amount of reading that boys do**. One of them is school literature, and reading preferences. Perhaps boys would be more inclined to read more if the literature in school was more in line with what boys prefer. A report from the Reading Centre clearly shows the **difference in preferences of literature** ("Gutter og lesing," 2008), where girls prefer social narratives, and boys more fun- and action-oriented, and fact-based texts. This raises the question of what we want to include in reading training in school. Is the actual acquisition of technical reading skill more important than the content of the literature read? What would happen if schools had comic strips for boys, and SMS texting for girls as starting points?

Another factor that influences boys' reading interest and willingness is how they handle being "worse than girls" at reading. For boys' academic achievement, there is a trend towards **underachieving when there is an expectation of being outperformed by girls** in the classroom (Hartley & Sutton, 2013). There has been a great focus on the underperformance of boys in reading, both in the media and academic institutions like the Reading Centre (Halsan, 2012). The heavy focus on the need to improve reading motivation and skill in boys may actually work both ways, as the boys grow older and learn that they generally perform worse than girls. Actions taken to improve motivation may be motivational for boys, but the heavy focus on the issue may also enhance the negative effect of the stereotype that boys are poorer readers. It cannot be ruled out that boys' expectations towards their own performance may influence their reading performance in a negative fashion.

Then there is the factor of **how boys and girls handle the testing situation itself**. While we do not know each child's interest and ability to concentrate at the time of testing, we know that girls are better at blocking out distractions and have better response inhibition at this age (van Deurzen et al., 2012). For a test that lasts just four minutes, a minor distraction, or lack of interest, will slow a child down considerably, thereby resulting in a poorer test score.

The **method of teaching children to read** may have influenced the sex gap. Children with poorer phonemic awareness, most often boys, are more likely to suffer under the current teaching method, and should be offered the initial phonemic reading training method (not the semantic method) to maximize their outcomes. Less skilled readers need explicit training to develop optimal pathways, while more skilled readers are basically fine in any training approach, phonological or semantic. (Clements-

Stephens et al., 2012). Perhaps the freedom to choose a reading training method ("whole language" method, "phonetic method" or "a mixture of these") amongst teachers in Norway (Lindbäck, 2003) should be evaluated in terms of method and reading outcome in boys and girls.
Within the present socio-cortico-cultural framework (G. M. Edelman, 1993; Gottlieb, 2007) girls will read more, and thereby become more skilled readers than boys because they exercise their slightly superior neural networks for reading more, earlier in life.

The consequences of differing ability, and the cultural, social and political factors of skill development deserve commentary, as these are factors that can be changed to improve reading skill in children, and possibly even out the differences between boys and girls in this domain.

One possibility is to **establish sex-differentiated norms for reading.** On the Word Chain Test, boys lag behind girls from grade 4 to 9, but when they reach grade 10 they perform equally well (Høien T, 1997), although the national assessments in grade 8 and 9 indicate that the sex gap in reading performance is still present (Utdanningsdirektoratet). As there is no national assessment of reading when children finish 10th grade in Norway, there is no way of knowing if the sex gap in decoding has closed at that point, as the results from the Høien et al. study suggest. Still, the grades boys and girls get at their final exams after 10 years in school, both in written and oral Norwegian, suggest that the performance gap is still very present ("Karakterer ved avsluttet grunnskole," 2012). Perhaps it would be useful to consider a sex difference in "academic expectation" for reading and writing, the languages in general, for the duration of the years when boys naturally lag in neural maturity, much like is found in physical fitness standards for older children (Welk et al., 2011).

Indications for further study

The psychological effect of sex-differentiated reading expectations may lead boys to perform better by not comparing themselves to girls. On the other hand, lowered expectations may further strengthen stereotypes and strengthen the performance discrepancy even more. An intervention study with different stereotypes augmented in the classroom may determine how this would influence boys' performance based on perception of ability. One possible drawback is that it would be difficult to “shield” the children from stereotypes presented elsewhere.

A study of sex-differentiated norm targets in reading may clarify if boys’ attitude towards reading, their own performance, and the amount of time spent on reading would benefit or be exacerbated by changes in expectations.

Also, boys’ motivation to read the material they are expected to read needs to be assessed. There is a challenge in designing reading training to be equally efficient in boys and girls, in terms of acknowledging the differences in underlying ability at different ages, and thus the need for different methods of training. The way the teacher talks about boys and girls, and reading expectations, and what is included in curriculum clearly also influences the motivation in boys to enhance their skills via reading more.

Studying the effect on reading in boys who have only been exposed to the phonemic method of instruction in the initial phase could confirm if this method is superior, or if other factors such as less motivation will hamper skills development. The issue of motivation has been used as reason to practice semantic, or mixed methods in Norway thus far (Lindbäck, 2003).

Physical Fitness

There was no significant difference between boys and girls on the physical fitness test as a whole. This is in accordance with what was expected.
The Fitnessgram Healthy Fitness Zone criteria are equal for boys and girls on aerobic capacity at 10 years of age (Welk et al., 2011), and we found no sex difference on tests of aerobic capacity.

Two of the subcategories of the fitness test differed in results for girls and boys.
The test items that differed, standing broad jump, and throwing a tennis ball, require explosive strength in upper lower limbs, an area where sex differences tend to be present in favour of boys (Marta et al., 2012). The differences in the task of throwing a tennis ball in favour for boys (p=.002), is in accordance with what Marta (2012) found.

However, the better performance of girls in the standing broad jump task (p=.022) could indicate that our sample was not representative of the overall population.

Still, these are children in a growth phase, and we did not assess pubertal status, amount of body fat, height or weight of the children in the study. These are all factors that are associated with standing broad jump performance (and other fitness measures) (Gonzalez-Suarez & Grimmer-Somers, 2011; Moliner-Urdiales et al., 2011), and are factors that might have shed light on this result.

Physical Activity

The boys and girls in our study were equally physically active.
From the national assessment of activity, we would have expected the boys to be more active than the girls (Kolle & Anderssen, 2012). However, there may be some contributing factors to the slightly unexpected result.

The self-report in our study was done in the months of March and April, where the general activity among boys and girls is slightly lower than in the summer months (Kolle E, 2012). **The time of year may thus have affected outdoor activity levels**. The study did not differentiate between indoor and outdoor activity, nor did it survey what type of activity was performed. We know that boys tend to engage more in ball games (Kolle & Anderssen, 2012), and that games like football are often played outdoors, which means that the season may have resulted in a misrepresentation of boys' activity level.

There is reason not to trust these self-reported data fully, because this approach to **measuring activity is only moderately reliable** in a population of this age. A review of different methods of self-report of physical activity showed a moderate validity (0.30-0.40), with great variability (0.16-0.88), with the weakest correlation for the youngest participants (Foley, Maddison, Olds, & Ridley, 2012).

Also, the concept of "activity that made you sweat" may not mean much to younger children, especially preadolescents, as they will need to be very active before even breaking a sweat. This is due to the body's natural development, and governed in part by hormones. This makes reporting physical activity a difficult task for younger children, and not very reliable. Also, the threshold for breaking a sweat or

becoming out of breath is strongly linked to how physically fit a person is (Fredriksen, 2000; Pedersen, 2006). This may therefore introduce small variations in the data, because those who are more fit may underreport their activity, and less fit children may overestimate their activity level. If this is the case, the smaller variation in activity data may further mask a possible activity effect on both fitness and the Word Chain Test.

The measure of duration of physical activity, tallied as hours on most active day, may be influenced by the **child's ability to judge duration of time**. There is a strong connection between deficits in phonological skill, and poorer executive function and perception of time duration (Gooch, Snowling, & Hulme, 2011). It is not unlikely that distractions will impair a child's ability to judge the duration of activity. It has been shown that distractions make children report shorter than actual duration of events (Zakay, 1992). Knowing this, we may assume that children who participate in fun, engaging, physical activity may become so absorbed in what they do that they "forget time", in other words are distracted, and possibly report a shorter duration of their physical activity.

The Word Chain Test, fitness, and physical activity

For the group of children as a whole there were no significant associations between the Word Chain Test and either physical fitness or physical activity. There was a low, but positive, correlation between fitness and activity, and a strong and significant correlation between number of active days per week and duration of activity on most active day. This is in accordance with the literature, and what we expected, except for the lack of fitness effect on reading where we expected at least a small effect. However, the literature is not conclusive as to this association for children in general.

We know from motor skill research that the correlation between performance on different motor tasks is very low in children (Haga, Pedersen, & Sigmundsson, 2008) and that the interrelation between performance on fine motor skills in adults is no larger than chance (Loras & Sigmundsson, 2012). Knowing that the interrelation between tasks within the modality of motor performance is so low, the expectation towards a spillover from physical performance to cognitive performance should be equally low.

The results thus confirmed the lack of spillover from the physical modality to the cognitive modality. However, if the variability in the data is compromised by the method of obtaining activity data, a possible association between either fitness or activity and reading could go undetected. The fact that activities were measured at a time of year when children are slightly less active may introduce a misrepresentation of activity level compared to possible fitness outcome of the activity, as fitness is gained over time, while the activity measure is seasonally influenced and lower in spring than in the summer months (Kolle E, 2012). Also, the uncertainties in the activity data mentioned earlier could mask associations we have not found, if they in fact exist.

Sex differences in the reading-fitness-activity associations

There was a significant correlation between the Word Chain Test scores and fitness scores in girls (.404). In boys there was a low negative correlation between these variables (-.138).

That there is an association does not mean that there is a causal link between the two. The correlation may reflect differing underlying abilities, or differences in skill acquisition and the factors that contribute to this (as previously discussed), or both. As boys were underachieving compared to the norm for the Word Chain Test, this may have influenced the low correlation.

However, there may be an explanation for the link between reading and fitness in girls. If two sets of skills share underlying neural networks, i.e. use the same resources in the brain, then these skills will share a portion of underlying ability. If the networks are in excellent condition, all skills that use them will benefit. This also means that exercising one of these networks may necessarily mean exercising the other, to the extent of relevant overlap of networks between the skills share the use of modalities. Reading and physical exercise share some neural networks, more so if the exercise involves a large cognitive load (Tomporowski, Davis, Miller, et al., 2008). If the neural networks of young girls are in excellent condition, perhaps there is a spillover from a more mature executive function to better motor control, giving girls that read more benefit, via executive function, in the planning of exercise as a goal-directed activity. There is some evidence of stronger executive functions in elite gymnasts compared to amateur gymnasts (Garcia Lopez & Burgos Postigo, 2012). The direction of the association may very well be bidirectional. Better executive functioning leads to better fitness, and vice versa. The presumed “spillover effect” from physical fitness may also be *to* physical fitness. The general lack of association between physical activity and physical fitness in girls, as confirmed in this study, may be in support of this hypothesis.

Either way, more fit children are better at activating and adapting neural processes involved in cognitive control to meet and maintain task goals. With increased cognitive demands, more fit children show greater activation of frontal areas at first, then a greater decrease (compared to less fit children) while maintaining a high level of accuracy. Differences observed in brain activation patterns show a function of fitness, thereby allowing greater flexibility in fit kids, an increased ability to allocate resources and suppress task-irrelevant distractors (Chaddock, Erickson, et al., 2012). As girls in general mature faster in these prefrontal areas, perhaps they also gain an earlier fitness effect on the use of the neural resources in this part of the brain, compared to boys. The more developed the area is, the more exercise will tune the wiring into perfection.

The association between motor performance and reading is also linked in the visual system. There is a motor component to reading in the eye movements, and it has been shown that there is a link between “clumsiness”, i.e. poor motor skills, and visual processing (Sigmundsson, Hansen, & Talcott, 2003). It has also been found that dyslexics have a deficit in visual processing that leads to poorer processing of rapid changes in their environment (Sigmundsson, 2005). This would reflect the fact that poorer underlying ability shows up in both fitness and reading skill assessments, thus yielding a correlation.

It has also been shown that children with motor deficits tend to participate in less voluntary physical activity than others (Fong et al., 2011). The amount of physical activity a child engages in may thus be influenced by their underlying physical ability. This may contribute to skill level differences when children with natural sports ability participate more in sports. Spending more time developing and refining skills leads to better skills. Perhaps the same happens in the divergent performance between boys and girls, where sex influences natural ability.

The study does not report what kind of physical activity the children engaged in. There is some evidence that aerobic fitness alone may contribute to executive function improvement, but at the same time that the kind of aerobic activity performed will yield different outcomes in executive function (Tomporowski, Davis, Miller, et al., 2008). Specifically, the authors found that running on a treadmill, which is not very cognitively demanding although aerobically demanding, will yield less cognitive outcome than a team sports game with sets of rules that require a continuous estimation of how other players will behave and planning ones' own behaviour. The latter activity is far more cognitively demanding, and may therefore tap into neural resources required by executive function. These neural networks in the prefrontal cortex mature late in adolescence.

We know that boys engage more in team sports at this age, for instance ball-playing, than girls (Kolle E, 2012) while there is no difference between boys and girls engagement in endurance sports. In view of the executive function hypothesis, this should give the boys more cognitive load in their exercise than girls. Girls, however, participate more than boys in aesthetic sports such as dancing, which is also cognitively demanding, and beneficial for motor skills and balance, where girls outperform boys.

While boys were less active than expected, there was still a positive correlation between their fitness and activity scores (days, .304, hours, .299), although it did not reach statistical significance. For girls this association was far lower (days, .004, hours, .148). This is in accordance with literature and expectations.

Indications for further study

The cross-sectional design of the study provides a snapshot of 67 children and their reading skill, fitness and activity levels. Overall our subjects were healthy, non-obese, children from middle class homes. A clear picture of any causality between either variable requires a longitudinal study, preferentially with intervention groups. It would be beneficial to introduce great variation in the subjects as well, such as with regards to obesity, or diseases like dyslexia, diabetes, etc.

Future studies should be advised to carefully design their interventions and variables to avoid interventions as occurred with (Kamijo et al., 2011), where a beautifully designed nine-month randomized control physical activity intervention was confounded by the content of the intervention. The intervention group had a threefold intervention, with not only an aerobic fitness enhancement, but also a nutritional component and a cognitively stimulating motor skill enhancement game. The effect of the intervention was thus not solely a result from aerobic exercise, but had a nutritional and cognitive training component as well. Attributing academic effects to physical activity following this kind of intervention is unfounded.

Conclusion

The findings in our study do not support a clear relationship between reading skills and either physical fitness or physical activity. Particularly for boys, we found no correlation between either activity level or fitness and reading. However, there was a positive correlation between reading skill and fitness in girls.

Since fitness has long-term health benefits, these findings do not suggest that schools should remove sports from the school curriculum. However, it may be advisable to reconsider which kinds of sports are offered. Physical activities with a cognitive load may yield a cognitive effect, provided they use neural networks that are developmentally in place. Thus, letting very young children engage in complex strategic rule-based sports may not have the same cognitive outcome as letting adolescents participate in the same sports. Similarly, having preadolescents run the treadmill for hours may result in great fitness, but will provide little or no cognitive effect. If schools want a greater cognitive outcome from sports, they should choose sports to complement the neural networks they want to enhance.

The results of this study suggest that there would be a benefit from adding additional hours in training the technical aspect of reading, reflecting the fact that one needs to practice a skill itself to become good at it. Given the sex differences in this age group, reading training may be improved by the choice of teaching methods that take into account the development of, and neural differences between boys and girls, beginning with strictly phonetic reading training, then expanding into mixed methods as reading skills improve, to ensure that technical reading skill levels will not hamper boys in developing reading proficiency.

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