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Kjønnsforskjeller i forholdet mellom lungefunksjon og responstid i verbal prestasjon hos friske ungdommer

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Preface

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Abstract

The association between lung function and cognition has been examined in adulthood and in old age, but few studies have investigated the relationship in early life periods such as in adolescence. Because development in adolescence involves remarkable physiological and psychological changes, it is important to explore closely the relationship between bodily functions and cognition. This study evaluated the lung-cognition association in 49 healthy teenagers between the ages of 16-18 years, and gender differences were also investigated. We measured Vital Capacity (VC) and cognitive functioning. As part of the cognitive evaluation, verbal abilities were assessed through three different tasks: phonemic verbal fluency, semantic verbal fluency and reading of short text. On each of the verbal tasks inspiratory measures were acquired during execution of the tasks. To evaluate the lung-cognition association, we used two approaches: First, we correlated the separate performances of cognitive abilities and lung function. Secondly, we correlated performance on verbal tasks with inspiratory airflow parameters (duration, peak and volume) measured during the response time of each of the verbal tests. Results showed restricted gender differences in neuropsychological tasks, while more evident gender differences were found in VC. Correlational results showed that inspiratory airflow measures were especially associated with phonemic fluency tasks, which measures executive functions. These findings suggest that abilities associated with performance in phonemic fluency may require more oxygen usage for an optimal performance.

Keywords: Adolescence, gender differences, inspiratory airflow, lung function, cognitive abilities, executive function, verbal abilities, verbal fluency, response time, processing speed

Abstrakt

Assosiasjonen mellom lungefunksjon og kognisjon har blitt undersøkt hos voksne og eldre, men få studier har undersøkt forholdet tidligere i livet, slik som i ungdomstid. Utvikling i ungdomstid involverer betydelige fysiologiske og psykologiske endringer, og dermed er det viktig å undersøke forholdet mellom kroppslige funksjoner og kognisjon nærmere. Denne studien evaluerte lunge-kognisjon assosiasjonen hos 49 friske tenåringer i alderen 16-18 år, i tillegg ble kjønnsforskjeller undersøkt. Vi målte Vital Kapasitet (VC) og kognitiv funksjon. Som en del av den kognitive evalueringen, ble verbale evner målt ved tre ulike oppgaver: fonemisk verbal flyt, semantisk verbal flyt og lesing av en kort tekst. Inspiratoriske parametere (inn-pust) ble målt i hver av de verbale oppgavene, samtidig som gjennomføringen av oppgavene pågikk. To tilnærminger ble benyttet i evalueringen av lunge-kognisjon assosiasjonen: Først, ved å korrelere separate prestasjoner i kognitive evner og lungefunksjon. I den andre tilnærmingen, ved å korrelere utførelse på verbale oppgaver med inspiratoriske luftflyt parametere (duration, peak og volume) målt i responstid for hver verbal oppgave. Resultatene viste få kjønnsforskjeller i de nevropsykologiske oppgavene, imens det var større kjønnsforskjeller i VC. Korrelasjonsanalysene viste at inspiratoriske luftflyt parametere var spesielt assosiert med den fonemiske flyt oppgaven, som måler eksekutive funksjoner. Disse funnene foreslår at evner som er assosiert med prestasjon på fonemisk flyt antagelig krever mer oksygenbruk for å oppnå en optimal gjennomføring.

Nøkkelord: Ungdomstid, kjønnsforskjeller, inspiratorisk luftflyt, lungefunksjon, kognitive evner, eksekutiv funksjon, verbale evner, verbal flyt, responstid, prosesseringshastighet

Earlier research have demonstrated the existence of a relationship between lung function and cognitive performance in various populations (Sachdev et al., 2006; Weuve et al., 2011). Mostly, studies have addressed different cohort groups from middle-aged to late adulthood (e.g., McPhee et al., 2013; Singh-Manoux et al., 2011). From a developmental point of view, it seems important to expand this line of investigation to earlier life stages, such as in adolescence. The present project is part of a major investigation within life-span development, carried out at the Department of Psychology, University of Tromsø. The main investigation aims to better understand different aspects of the lung-cognition relationship in healthy teenagers. In this present subproject, we seek to evaluate lung function and its association with response times during verbal tasks as well as the possible effect of gender on this relationship. In order to provide a comprehensive framework to this study, a short review of the literature will comprise; cognitive and biological development in adolescence; gender differences in adolescence regarding cognition and lung function; information of earlier studies assessing lung function as well as methods related to its assessment. At the end of the introduction, the objective of this subproject together with the specific aims and hypotheses of the study, will be presented.

Biological and cognitive development during adolescence

Adolescence marks the transition from childhood to adulthood. It is a life period characterized with extensive development, involving important physical and hormonal changes in addition to brain maturation – and thereby cognitive development (Blakemore & Choudhury, 2006). In general, the teenage body undergoes remarkable bodily and physiological changes. Some of these changes relate to increment in muscular strength, agility and cardiorespiratory capacity (Ortega, Ruiz, Castillo, & Sjostrom, 2007) as well as important endocrine adaptations (Vigil et al., 2016). In parallel, the brain also endures important structural and neural changes, which occurs side by side with maturation of specific cognitive abilities. During adolescence, most brain regions are fully developed (Huttenlocher, 1979; Huttenlocher, De Courten, Garey, & Van der Loos, 1983; Yakovlev & Lecours, 1967). However, maturation of the prefrontal cortex and ongoing of myelination in the same brain area occurs until late teenage years (Vigil et al., 2016; Yakovlev & Lecours, 1967). Many researchers expect a correspondence between the frontal lobe maturation and development in executive functions (EF), which are higher-order abilities for the planning and control of behavior as well as rational thinking (Becker, Isaac, & Hynd, 1987; Blakemore & Choudhury, 2006; Casey et al., 1997; Lurija, 1973; Welsh & Pennington, 1988). An additional brain-behavior change that is relevant in adolescence relates to the increasing of axonal myelination, which lasts until the earlier twenties. Increased myelination enables faster neural transmission (Blakemore & Choudhury, 2006; Brodal, 2013) and hence, it allows teenagers to gradually process information more efficiently (Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001; Paus et al., 1999; Sowell, Trauner, Gamst, & Jernigan, 2002; Steinberg, 2005). Finally, improvement of problem-solving skills has been associated with optimized connectivity, or in other words with decremented changes in frontal lobe's synaptic pruning (Blakemore & Choudhury, 2006; Brodal, 2013; Huttenlocher, 1979; Woo, Pucak, Kye, Matus, & Lewis, 1997; Zecevic & Rakic, 2001).

Gender differences in adolescence

As mentioned in the previous section, the endocrine system plays a very important role in the onset of puberty and appearance of sexual characterization in both genders (Vigil et al., 2016). Probably for this reason many researchers have studied the sexual dimorphism in the teenage brain (Ingalhalikar et al., 2014; Koolschijn, Peper, & Crone, 2014; Vigil et al., 2016) and its relevance for cognition (see section below). From this standpoint, it has been a huge interest to further understand whether gender differences exist across a variety of functions and cognitive abilities. A brief summary of the most important findings at this respect follows.

Cognitive functions. Cognitive functioning improves in childhood and adolescence. In general, abilities related to cognitive control become more efficient, such as working memory, response inhibition, adaption, complex reasoning (Gazzaniga, 2014) and processing speed (Tourva, Spanoudis, & Demetriou, 2015). There are great individual differences in cognitive function among teenagers (Kimmel & Weiner, 1995; Steinberg & Lerner, 2009), and some researchers (Maccoby & Jacklin, 1974) argues that one possible reason for such differences might be related to the gender. The brain in males and females are physiological and biological different, and even though it has not been proved, one can assume that these characteristics may influence cognitive abilities in boys and girls (Vigil et al., 2016). Some researchers, like for instance Ingalhalikar et al. (2014), tries to link hormonal effects on brain development with gender differences in cognition. One good example is the fact that hemispheric dissimilarities in teenagers has been associated with better execution in motor and spatial abilities among males, while memory and social cognition skills seem to be better in women (Ingalhalikar et al., 2014). However, in spite that the brain in males and females is physiologically different, there is no clear consensus among researchers about whether teenage boys and girls present different psychological and cognitive capacities.

Currently, there are two theses addressing gender differences in cognition: The differential and the similarity hypothesis (Hyde & Anderson, 2005). The most popular one is the differential hypothesis, which suggests that males and females are psychologically quite different, for instance common general beliefs are that women are better communicators and show more emotions than men do, whereas men tend to be more logical and superior in object orientation. The similarity hypothesis in contrast states that genders in all ages have more in common than they are different, though, not for all psychological variables (Hyde & Anderson, 2005). To settle this controversy, Maccoby and Jacklin (1974) employed meta-analytical methods to find whether important gender differences existed. Results showed that for mathematical and visual-spatial abilities boys were more skilled than girls. As for girls, results showed that they were more accomplished than boys in verbal abilities. However, these differences were reported in the 1970's, and an update was necessary. For this reason Hyde and Anderson (2005) conducted a new meta-analysis regarding gender differences in major psychological functions. These authors reported a different conclusion than the one presented by Maccoby and Jacklin (1974), namely that as a whole both genders performed rather similar (78 % of effect sizes were small or close to zero) in a broad range of cognitive abilities.

Because the topic of gender differences is still on debate with contradictory findings in different type of functions, it is necessary to further update our knowledge about gender differences on functions that reach maturity in late adolescence, such as executive functions (EF) and processing speed. Due to the purpose of the present study, a short update on gender differences in verbal tasks is also of interest.

Executive functions. EF relates to an umbrella term of high-level capacities in charge of modulation operations of other cognitive processes (Anderson et al., 2001; Smith & Kosslyn, 2009). For instance, EF modulates the ability to organize thoughts (Jurado & Rosselli, 2007). P. Anderson (2002) proposed a model dividing EF into different components (subcomponents listed in brackets): attentional control (selective attention, response inhibition, self-monitoring and self-regulation), information processing (efficiency, fluency and speed of processing), cognitive flexibility (working memory, shift attention and conceptual transfer) and goal setting (initiating, planning, problem-solving and strategic behavior). Teenagers gradually gets better in modulating all these processes.

As previously mentioned, EF are dependent upon the entire brain, but these functions seem to be more associated with frontal cortex and in particular to the prefrontal area (Anderson et al., 2001; Blakemore & Choudhury, 2006; Casey et al., 1997; Gazzaniga, 2014;

Tamm, Menon, & Reiss, 2002), therefore some authors label them as “frontal lobe functions” (Stuss, 1992). Since EF relies on brain areas that in adolescence are not fully developed, teenagers naturally have more difficulty in accomplishing EF-related tasks. The reason is because they still have immature brain mechanisms necessary to achieve these functions (Blakemore & Choudhury, 2006). At the same time, since executive control gradually improves during adolescence, teenagers are better equipped than children to complete EF-related tasks. Kalkut, Han, Lansing, Holdnack, and Delis (2009) argue that gender differences in frontal lobe development might be linked to differences between genders in EF as well. Kalkut et al. (2009) suggested that development in EF in teenaged girls occurs earlier since girl’s maximum peak of grey matter is reached before that of boys (11 years in girls, and 12 years in boys) (Giedd et al., 1999).

Notwithstanding, findings in gender differences in adolescents are inconsistent. Boelema et al. (2014) investigated maturation of EF in early and late adolescence (age range: 11-19, N = 2 217) using a longitudinal design, and examined the subcomponents of focused attention, inhibition, sustained attention, speed of processing, working memory and shift attention. Results from this study demonstrated significant gender differences in all of the subcomponents (expect focused attention), though in an unexpected direction. Contrary to earlier beliefs, the results showed that boys matured more rapidly than girls in most skills (working memory and sustained attention, inhibition) all through the adolescents years (age range: 11-19). Although scores on processing speed in boys were better at age 11, girls improved more later on in processing speed over the course of adolescence (Boelema et al., 2014) which is consistent with findings from another study (Anderson et al., 2001). Early in adolescence (mean age: 11) boys scored higher for shift attention, but their performances were equal to those of girls in the following years towards 19 (Boelema et al., 2014).

Also the study of Kalkut et al. (2009) showed gender differences in EF among young individuals (age range: 8-30), whereby females in general demonstrated better performance. However, Kalkut et al. (2009) also found that the interaction of age-gender explained EF-performance, suggesting that improvements in EF are present at different age-stages between genders. Thereby, boys and girls might follow different developmental paths in EF being better at certain skills at different times. Related to this idea, Kalkut et al. (2009) argues that in spite of the general acceptance that EF improves with age, we still do not know of the exact developmental variations in EF during adolescence.

Processing speed. Cognitive maturation in adolescence is hypothesized to be partly determined by processing speed (Kail & Steinberg, 1991), which is a fluid ability indicating brain's efficacy to register and process information (Tourva et al., 2015). The term "mental speed" is often used to describe processing speed (Jensen, 2006). Response time/reaction time (RT) is the standard way to operationalize processing speed (Jensen, 2006). RT is defined as the time it takes to perceive a stimulus and respond to it, and this involves both motor and cognitive processes (Woodruff-Pak, 1997). For instance, if an individual were to process a visual stimulus, perceiving involves sensory transduction retina and perception, while responding involves language processing which includes activation of speech muscles (respiratory, phonatory and articulatory).

Processing speed changes during the different life periods, and in general, children are considerably slower in their responses compared to young adult's RTs. Furthermore, RT is at its highest levels during the 20s (Cerella & Hale, 1994; Jensen, 2006; Kail & Steinberg, 1991). Similar to Francis Galton's old measurements of response time in 1884-85 (Koga & Morant, 1923), Kail and Parke (1991) found consistent age differences in processing speed throughout childhood and adolescence, in which children's responses rapidly becomes faster during childhood (RTs decreases) and their RTs continues to decrease through adolescence but in a slower pace. It is proposed that teenagers responds faster than children because they have more practice and expertise needed, and a more matured nervous system (Kail, 2008). Anderson et al. (2001) suggest a growth spurt in processing speed around 15 years of age. Older teenagers demonstrate quicker speed performance when compared to their younger counterparts (Anderson et al., 2001; Luna, Garver, Urban, Lazar, & Sweeney, 2004; Tamm et al., 2002). All studies evaluating RTs in adolescence are unanimous in indicating that responding rate, i.e. processing speed, improves with increasing age in adolescence.

Regarding gender differences in processing speed it seems to be dependent upon *type* of task, meaning that males and females show faster responses in different kind of tasks. A review on this topic (Roivainen, 2011) compared studies regarding processing speed of males and females across the life-span. The review found that females in general were faster in processing speed tasks like naming, digits and alphabets tasks; while male's processing speed were faster in finger tapping, and in tasks measuring simple and complex RT. Camarata and Woodcock (2006) found highly significant gender differences in performances on processing speed tasks (naming, matching and decision tasks) across the life span (N = 4253, age range: 5-79) and amongst teenagers (n = 414, age range: 14-18), whereby females demonstrated faster processing speed compared to males; especially during adolescence. Camarata and Woodcock (2006) discuss in their article that the gender differences in processing speed observed among teenagers, might be connected to gender differences in myelinization ratio.

Other researchers (Benes, Turtle, Khan, & Farol, 1994) have found that female's myelin ratio are higher than in males between the ages of 6 to 29, and especially during childhood (age range: 6-11) and adolescence (age range: 12-19), though these data might need to be updated.

Verbal abilities. Cognitive functioning includes verbal ability, which is a collective term of different verbal components. Verbal abilities are important skills in everyday living and central to virtually all academic pursuits (Hyde, Linn, & Masters, 1988). According to Campito and Sternberg (1994) the term refers to an individual's amount and structure of verbal knowledge (also called vocabulary) and the ability to make use of this knowledge in reasoning (cognitive processing). Various verbal tasks assess verbal ability, and most important of all is that most of the tests evaluating different cognitive functions are evaluated through a verbal response. Hyde et al. (1988) suggest that basic language processes are usually involved in evaluation of various cognitive abilities, such as retrieval of a word for memory assessment, or of a picture's name; analyzing relations among words for evaluation of semantic memory, selection of relevant information from extensive information and written/oral verbal production, etc. Thus, verbal tests are useful when evaluating memory, response time, speech production, and EF.

Some specific tasks that are verbal in nature and that furthermore assess different cognitive processes are verbal fluency tasks. Verbal fluency refers to the ability to give a free verbal recall either written or oral that matches a phonemic or a semantic rule. For that reason, verbal fluency tests (VFT) are divided into phonemic and semantic types. VFTs involves generating as many words as possible within a time window, either beginning with a designated letter in phonemic task (like F, A or S) or words belonging to a category (such as animals or fruits) in the semantic variant. Furthermore, there are often rules adding difficulty to each task such as forbidding proper nouns, repetitions or variations of already mentioned words (Rodríguez-Aranda, 2006). The speed and ease of word production are equally important in VFTs and not only the words' meaning (Rodríguez-Aranda, 2006).

Appropriate performance on phonemic VFT mainly reflects executive aspects of language and executive search strategies of memory retrieval (Phillips, 1997; Whelihan & Lesher, 1985). Both phonemic and semantic fluency involves switching on effective search processes and clustering ability, thought depending upon our personal mental store of available words (vocabulary knowledge) (Bryan & Luszcz, 2000). Research suggest that it is more difficult for healthy participants to generate words by letters (phonemic), than words belonging to a semantic category (Diaz, Sailor, Cheung, & Kuslansky, 2004; Strauss, Sherman, & Spreen, 2006). In contrast, semantic fluency depends mostly upon well-organized semantic memory (vocabulary knowledge) (Kremen, Seidman, Faraone, & Tsuang, 2003), formal education and cultural background (Da Silva, Petersson, Faísca, Ingvar, & Reis, 2004).

The above information about VFTs is noteworthy when studying cognitive development in adolescence as one of the VFTs evaluates executive functions, and thus, application of these tests is suitable for assessment of EF during adolescence. Few researchers have examined VF performance in healthy young individuals. In fact the most recent meta-analysis (Rodriguez-Aranda & Martinussen, 2006) on the field shows that only three studies have examined VF in individuals under the age of 18 (Ardila, Ostrosky-Solis, Rosselli, & Gómez, 2000; Tombaugh, Kozak, & Rees, 1999; Yeudall, Fromm, Reddon, & Stefanyk, 1986) using Controlled Oral Word Association Task (A. L. Benton, 1967). In these studies large age ranges (for instance 16-59 in Tombaugh et.al 1999) makes it difficult to describe the nature of VF in adolescence.

Results concerning gender differences in verbal abilities are not clear. On one side, the old idea that females acquire language skills earlier than males and that females are superiors in verbal abilities is no longer an accepted fact. The textbook of Maccoby and Jacklin (1974) argued in the 60s that gender differences existed after 11 years of age and in favor of females. Maccoby and Jacklin (1974) stated that girls have an earlier language acquisition, speak in longer sentence, articulate clearer, are more fluent, are the first to learn how to read, and show better performance in both spelling and grammar compared to boys. On the other side, a more recent comprehensive meta-analysis (Hyde et al., 1988) surveying 165 studies with over 1.4 million participants provided strong evidence against the old believe: There are no gender differences in verbal ability, at least not among American teenagers. Wallentin (2009) argues that female's early advantages in verbal abilities disappears when children grows older. Hyde et al. (1988) states that there is little knowledge about the advocated nature of gender differences in verbal abilities. Hyde and Anderson (2005) clarifies that gender differences in verbal abilities might grow larger or smaller at different times during the life span – for instance genders could be more equal in some of these abilities in one period of life, but more diverse at another age stages. Camarata and Woodcock (2006) found a small, significant gender difference in verbal ability across the life span (5-79), with males overall demonstrating better performance compared to females and also in adolescence (age range: 14-18).

In verbal fluency tests, research on gender differences in adulthood is also ambiguous regarding especially phonemic fluency tasks. Some researchers have found that women's performance is better in phonemics compared to males in young adulthood (Heister, 1982;

Weiss, Kemmler, Deisenhammer, Fleischhacker, & Delazer, 2003a). In opposition, others (Bolla, Lindgren, Bonaccorsy, & Bleecker, 1990; Ruff, Light, Parker, & Levin, 1996; Tombaugh et al., 1999) have found that the effect of gender is small on VF performance among adults and elderly. According to Wallentin (2009) gender differences disappears when the sample size is large, for instance (Weiss et al., 2003a) who found a gender effect had a small sample (N = 97); whereas Tombaugh et al. (1999), who did not find any gender differences, had a sample of 1300 participants. Capitani, Laiacona, and Basso (1998) discovered that male's verbal fluency decline in older age, which was not the case for females. To our knowledge, there are little research examining gender differences in teenagers VF performances. One study (Porter, Collins, Muetzel, Lim, & Luciana, 2011) observed that VF is affected by age-gender interaction in adolescence, whereby teenaged girls tended to reach peak performance earlier than boys.

The association between cognition and lung function: Is it important for cognitive development?

Breathing is a vital function controlled by autonomous mechanisms, and our respiratory function is physiological responsible for providing oxygen, remove carbon dioxide and maintaining acid-base balance (e.g, Harding, Pinkerton, & Plopper, 2004; Ley, 1999). Though, not obvious, breathing is also implicated in psychological functions (Ley, 1999) and thus, it is highly connected to our mind. Oxygen plays an important role in brain metabolism, and transport of glucose across the blood-brain barrier is dependent on oxygen (Lund-Andersen, 1979; Pardridge, 1983). Breathing affects cognitive performance, and many studies have found that it is associated with better memory (D. Benton, 1990; S. Craft, Murphy, & Wemstrom, 2013; S. Craft, Zallen, & Baker, 1992; Manning, Hall, & Gold, 1990) with respect to enhanced consolidation (Scholey, Moss, & Wesnes, 1998), improved long-term memory and also greater attention (Moss & Scholey, 1996; Scholey et al., 1998). Furthermore, an impaired respiratory function increases risk of mortality (Hole et al., 1996) and can cause changes to the central nervous system (CNS), like hypoxia or vascular disease, which has a negative impact on cognitive function (Richards, Strachan, Hardy, Kuh, & Wadsworth, 2005).

Breathing and lung function. Breathing is the process of moving air out and in of the lungs (Harding et al., 2004), and therefore measuring lung function provides solid information of the respiratory system. The respiratory system consists of the upper and lower respiratory tract. The upper tract includes the nose, pharynx and larynx, while the lower tract consist of the trachea, bronchi, bronchioles and alveoli. Other important parts of the system are capillaries, arteries, veins and blood. The lung function's main role is ventilation, diffusion and perfusion (e.g, George, 2005). The physiological function of the lungs is the exchange of carbon dioxide, which is necessary for cellular activity. The lungs provide a surface area of respiratory membrane, where gaseous exchange occurs, with oxygen entering the blood and carbon dioxide removed from the blood (George, 2005; Shiner & Steier, 2013).

The lung function during the life span. Changes in the growth and maturation of the lungs may be of importance for cognitive development. In childhood lung function increases linearly until adolescent growth spurt (10 years for girls, 12 years for boys) (Wang, Dockery, Wypij, Fay, & Ferris, 1993), and the relationship between height and age increases in the same manner. Gender differences in lung function increases with height among children, and thereby girls who reaches growth spurt before boys tend to have higher respiratory values (Rosenthal et al., 1993). Lung function increases rapidly during puberty; indicating that this is an important period for lung development (Rosenthal et al., 1993). Pubertal stage also affects lung function, whereby respiratory advantages are connected with early puberty and respiratory disadvantages when pubertal development occurs at a later stage (Rosenthal et al., 1993).

In adolescence, gender differences in lung function are significant. Rosenthal et al. (1993) argues that respiratory measures (e.g. Forced Vital Capacity) is affected by muscle strength, which often increases more in boys compared to girls. Moreover, Rosenthal et al. (1993) discuss that thoracic proportions that increases more in boys during growth spurt (DeGroodt, van Pelt, Borsboom, Quanjer, & van Zomeren, 1988), might affect and cause gender differences in lung function.

Lung function appears to be stable when girls reaches the age of 16 and boys 18. Lungs continues to gradually grow to peak of fully matureness at 20 years of age in girls and 25 years in boys and thereafter decreases (Janssens, Pache, & Nicod, 1999). Normal aging is associated with decreased lung function, and common physiological changes in old age are stiffening of chest-walls and more distensible lungs, resulting in increased residual volume and decreased Vital Capacity (Janssens et al., 1999).

Measuring lung function. Spirometry is the standard technique to examine lung function, and performed with an apparatus called spirometer. A spirometer provides different respiratory parameters that reflects lung function, such as Vital Capacity (VC). VC is a measure of the greatest air amount possible to exhale from lungs after maximal inhalation, meaning that the participant inhales maximally and thereafter exhales as rapidly and forcefully as possible into for instance a breathing mask (KayPENTAXa, 2006). For this reason many researcher calls this measure “Forced Vital Capacity, FVC”. VC often consists of three reflecting sub-measures: expiratory airflow duration, peak expiratory airflow and expiratory volume (amount of air in lungs) (KayPENTAXa, 2006).The spirograph shows results, placing the cumulative volume on the y-axis and time on the x-axis. Forced expiratory volume at 1 second (FEV_1) is also a common used measure of lung function. FEV_1 is similar to FVC expect that it only measures how much air volume is expired during the first second after filling the lungs to the maximum (Skjønsberg, 2014).

Previous research showing association between lung function and cognition in the life-span. To date, most studies examining the lung-cognition association have proved the existence of such interrelation in middle-aged and older adults. For example, one longitudinal study (Emery, Pedersen, Svartengren, & McClearn, 1998) among middle-aged and elderly twins, found that FEV_1 predicted performances in tasks measuring fluid abilities, but not in crystallized abilities. Consistent with the mentioned findings, Anstey et al. (Anstey, Windsor, Jorm, Christensen, & Rodgers, 2004) also demonstrated that FEV_1 correlated significantly with cognitive tests among middle-aged adults (age range:40-44). Poor cognitive function in early adulthood have been found to be associated with reduced lung function (FEV_1) in middle-aged (Carroll, Batty, Mortensen, Deary, & Phillips, 2011). Some have also concluded that reduced lung function relates to poorer cognitive function and decreased subcortical atrophy in mid-life (Sachdev et al., 2006). In older adults Albert et al. (1995) found that measures of lung function was among the best predictors of cognitive changes and higher respiratory values were associated with less cognitive change. Several other studies corroborate the above data (Allaire, Tamez, Whitfield, & Allaire, 2007; Anstey et al., 2004; Singh-Manoux et al., 2011) (Weuve et al., 2011). Furthermore, Singh-Manoux et al. (2011) proposed lung function as an overall measure of functioning in early old age.

As for young adults the lung-cognition association has also been explored (Anstey et al., 2004). The study by Anstey et al. (2004) found significant correlations between lung function (FEV1) and performance on the cognitive tests immediate recall, digits backward, vocabulary, symbol-digit modalities tests and reaction time in a cohort of young adults between 20 and 24 years of age. In contrast, another study (Allaire, Tamez, Whitfield, & Allaire, 2007) failed to find any significant correlation between respiratory measurements and cognitive tests among young adults.

Regarding studies early in life, only scarce number of studies have investigated the matter in children or teenagers. For instance Suglia, Wright, Schwartz, and Wright (2008) correlated 6-year old children’s lung function (FEV_1, FVC and forced mid-expiratory flow rate) with scores on cognitive tests (Wide Range Assessment of Memory and Learning, and Kaufman Brief Intelligence test) measured later at 9 years of age. Consistent with findings in adult samples, Suglia et al. (2008) found that increased FEV_1 and FVC were associated with increased cognitive development.

To our knowledge, only one study with adolescents has been performed (Richards et al., 2005). In this investigation, the authors found that cognitive ability at 15 years of age were associated with lung function (FEV_1) at 43 years. Those with better cognitive performance as teenagers, also had better lung function (FEV_1) when middle aged.

Relevance of measuring lung function in adolescence. Some reports (Anstey, 1999; Emery et al., 1998) suggest that lung capacity measured with Vital Capacity is a biomarker of biological and functional aging, but it is still uncertain if respiratory mechanisms also could be used as biomarkers of maturation in adolescence that may be relevant to judge cognitive maturation. If there exist a clear association between lung function and cognition in teenagers, as it is in adults and elderly, lung capacity could be used not only as a health marker (Ortega et al, 2008) but also as an indicator of maturity level, in the same way as RTs reflect maturation of central nervous system (Cerella & Hale, 1994; Kail, 2008). Information of the lung-cognition association in teenagers would also expand our understanding of its role in life-span development.

Aims and rationale of the present study

The present study evaluates lung and cognitive functions among healthy teenagers as well as the association between lung measures and cognition and the possible effect of gender on this association. Since executive functions and processing speed are abilities that still develops in late adolescence, we wish to evaluate the role of lung function on EF and processing speed. Specifically, we aim to answer whether improved lung function is associated with faster and more precise performance in tasks measuring EF. In previous investigations the association between lung function and cognition, have been performed by measuring separately both set of functions and then correlations have been drawn between the different outcomes. However, we believe that the best way to apprise the interrelationship is to evaluate both capacities, i.e. lung function and cognition *at the same time*. Such an evaluation can only be performed with adequate instrumentation that allows the use of spirometry at the exact time of task performance, that is, during speech production/answer generation. For this reason, we decided to evaluate lung function during execution of verbal tests.

We employed both variants of verbal fluency tests (VFT), semantic and phonemic, because they evaluate different cognitive requirements, i.e., semantic memory and EF correspondently. At the same time, both VFTs also assess processing speed, which may vary depending on the type of VFTs demands. For the above reasons, we measured response times (RTs) in both tasks, expecting that difficulty level for each task would be reflected in the required time to produce a correct answer. In the case of VFTs we believed that the phonemic variant would be the most demanding for teenagers as they primarily assess EF, while the semantic variant should be less difficult. During performance of VFTs, we also measured the inhaled air during RTs. We selected “inspiratory airflow” as the measure of lung function and RTs as the measure of processing speed during sematic and phonemic VFT.

Inspiratory airflow was chosen among other spirometry parameters because it accounts for amount of air required in the various verbal tasks. Before speaking, we rapidly inhale air and thereafter speak on exhaled air (egressive) (Ashby & Maidment, 2005). Inspiratory airflow is thus, dependent on voluntary control over inhalation during speech production compared to silent non-speech breathing. Breathing is affected by speech-related planning, which is assumed to be cortically generated (Denny, 2000). Denny (2000) argues that the variability in inspiratory breathing, in form of inspired lung volume, is partially relying on autonomous processes. This means that much of the variability in the amount of air inspired relies on voluntary control directed by cognitive processes.

Based on the above rationale, the main goal of the study is to examine the interrelationship of inspiratory airflow measures with response times during verbal fluency tests in healthy adolescents. As a control condition, we also used a simple reading task, considered to have low difficulty level, on which we also measured airflow and RTs. Moreover, since the study of gender differences has been an important topic in cognitive development, especially associated to verbal abilities (believed to be better among females), we also aim to address the differences between boys and girls on the association between inspiratory airflow and RTs in verbal tests. Besides this main goal, the study will also employed the regular approach of measuring general cognitive abilities and lung function separately (via Vital Capacity), in order to conduct correlational analyses across datasets. To our knowledge, no previous studies have examined this interrelationship among teenagers. The study intend to explain physical maturing processes, both due to cognitive and respiratory development.

Thus, to sum up the present study will determine the association between lung function and cognitive abilities in healthy adolescents, by examining three specific points:

A) Gender differences in lung capacity (VC), cognitive function (test battery), response times (RTs) in three verbal tasks and inspiratory breathing during three RTs.
B) Association between lung capacity (VC) and cognitive function (test battery) when assessed separately.
C) Inspiratory breathing (inspiratory airflow) during reaction times in three verbal tasks (VFTs and reading of a text.

Hypotheses. The hypotheses for each of the mentioned points are as follows:

A) We expect to find gender differences in lung capacity (VC) and inspiratory airflow measures, where boys show better VC and greater inhalation due to their bigger body size and height compared to girls. Since the last meta-analytic study (Hyde et al., 1988) showed that girls and boys do not differ considerably in general cognitive function, we do not expect to find different performances in general neuropsychological performance (test battery). However, several studies have found that females tend to perform better in phonemic fluency tasks, we therefor hypothesize higher scores in phonemic fluency performance (number of correct produced words) in girls compared to boys. Furthermore, various reports (Camarata & Woodcock, 2006; Roivainen, 2011) showed that females are faster in speed tasks involving alphabets, we therefor hypothesize faster response time on the VFTs in girls compared to boys.

B) We hypothesize that the teenagers VC-measures should be to some degree significantly correlated with performances on some of the tests from the neuropsychological battery because previous research have found the lung-cognition association to be significant in all other life periods (childhood, adulthood and in old age). At the least, we expect that VC would be correlated with psychomotor function due to the common element of muscular involvement.

C) Since higher inspiratory volume during RT may reflect more need of lung capacity usage, higher inspiratory volumes are expected in those verbal tasks requiring higher cognitive resources. We thus, hypothesize that as a whole, VFTs needs more resources to be processed than simple reading of a text and we expect to observe more inspiratory volume to accomplish these tasks. Difficulty of a verbal task means RTs with longer time durations (in seconds) (participant use longer time to respond) and thus if there is an association with lung function, also higher airflow use. Since EF is still developing in adolescence, and phonemic verbal fluency requires EF, we hypothesize that this specific task would need the highest inspiratory volume as compared to the semantic task.

Method

Participants

Because the purpose of this research was to clarify the nature of the lung-cognition association in a normal population, only healthy participants were included. The sample consisted of 49 healthy teenagers (23 boys, 26 girls), aged 16 to 18 years (M = 16.61, SD = .73). All participants spoke Norwegian as their first language and all were right handed. They had no history of asthma or neurological abnormality. Former project associates (Wahlmann & Henriksen, 2014) had already recruited 22 participants. The present study completed the data set with 27 new participants. The new participants were recruited from randomly selected local high schools from North-Norway, after presenting the project in classrooms and inviting teenagers to voluntarily participate. In addition, recruitment were also performed by sharing handouts of flyers and having stands at high schools. A detailed description of the study was provided to interested participants, clarifying that participation was of free will and that everyone may stop the examination at any point if they wished so.

Health was measured by an interview asking questions about physical health and by participant's own self-rating of physical condition as good, medium or bad. Beck Depression Inventory (BDI) screened participants for depression, and 12 participants from the whole sample were excluded from the study as they scored over a cut off over 11 (> 10 = mild depression; > 19 = major depression) (Beck, Steer, & Carbin, 1988). Because the main project at the Department of psychology investigates life-span cognitive changes in various populations of elderly adults, the Mini-Mental State Examination (MMSE) was also used. Although, the MMSE is mostly used for older adults to assess cognitive functioning, and it should seem strange or unnecessary to apply it to teenagers, we decided to adhere to the common test battery in the main project. Additionally, fifteen participants were excluded due to technical troubles.

Before testing participants signed a written consent, and those under 18 also provided a signature from their parents. Subjects were rewarded with a free cinema-ticket for their participation, and travel expenses were covered. Data collection took place during the autumn semester of 2016. The Regional Research Ethics Committee (REK) approved the study.

Materials

The present study used an experimental design developed in an earlier study (Rodríguez-Aranda & Jakobsen, 2011). This design included a test-battery of neuropsychological tests (cognitive and psychomotor tasks), respiratory and verbal tasks.

The design allowed measuring breathing *at the same time* as speaking in verbal tasks. See below for a detailed description of the test battery. A former study (Rodríguez-Aranda & Jakobsen, 2011) has also used and described the same material.

Background information. An initial interview gathered background information about demographics, physical and mental health. Participants gave a self-rate of physical health, ranging it as good, medium or bad. Questions asked about age, medication use, any experiences of head trauma, stroke, asthma, smoking and drinking habits, engagement in physical activity, neurological disorders etc.

Beck Depression Inventory (BDI). BDI (Beck, Ward, Mendelson, Mock, & Erbaugh, 1961) screened for depression. BDI consist of 22 groups of statements, and participants were instructed to choose one sentence in each group that described their last week's feelings. A BDI score under 10 is considered as "not depressed", a score over 10 as "mild depression" and a score of 19 or higher as "major depression" (Beck et al., 1988).

Mini-Mental State Examination (MMSE). The Norwegian version of MMSE (Folstein, Folstein, & McHugh, 1975) was used to assess general cognitive status, by testing attention, recognition, orientation, recall, naming, comprehension, and short-term memory. Maximum score of the MMSE test is 30, and each correct answer gets one point. Examiner followed standardized instructions. Regular cut-off for exclusion is 24.

Cognitive tasks. Administered tasks measured different cognitive abilities, whereby some reflected aspects of executive functions and others tested abilities that are more general. Tasks measured language, different aspects of memory, attentional control, attentional capacity and knowledge of words.

Logical memory part 1 and 2. Immediate and delayed memory were tested by a Norwegian version of the subtest "Logical memory 1 and 2" from Wechslers Memory Scale (WMS-III) (Wechsler & Nyman, 2008). The examiner reads a story (the Anna Jensen story), and after the reading asks the participant to give an immediate free recall. The examiner reads the story one additional time, and instructs the participant to keep the story in mind to give a delayed recall 30 minutes later. Maximum score of the Logical Memory test (LM) is 25, whereas each remembered item gets one point. A digital audio recorder collected answers.

Stroop test. A standard Norwegian translation of the Stroop test (Golden, 1978) was applied. The test consists of three parts, all with standard formats. Each part lasted 45 seconds, and a digital stopwatch ensured accurate time. All formats included a matrix of 20 rows by 5 columns. In the first task, the format consisted of 100 written words (e.g., red, blue, green) in black ink. Instructions were to read as many words as fast as possible during the fixed time, and total number of read words were counted. All words in the format of the second task were replaced with “XXXX” printed in randomly colored ink (e.g. red, blue or green). The task was to name as many items as possible, afterwards the correct named items were counted. In the last task, a format with 100 written words with ink in different color was applied. Instructions were to name items and not read words. Correctly named items were registered. The different color-word task involved inhibition of inappropriate responses and indicates attentional control; this task typically produces slow responses because of failure to inhibit the habitual response of reading or selective attention error (Lezak, 2012).

Vocabulary. Word knowledge (lexical level), a crystallized ability, was measured by the Norwegian translated sub-test Vocabulary from WAIS-R (Wechsler, 1981). The task was to explain or define 33 words with ranging difficulty. Answers were analyzed and coded following standardized instructions.

Digits Span. The sub-test Digits Span from WAIS-R (Wechsler, 1981), including the two tests Digit Span Forward and Digit Span Backwards, was applied to test working memory capacity (short-term retention) and the aspect of attentional control in executive functions. Digit Span consists of sequentially auditory-verbal stimuli, from which the examiner slowly reads aloud (one number per second) seven pairs of random number sequences. The participant is instructed to give an immediate verbal recall after each number sequence. Difficulty in the test increases when the sequences gets longer and there are more numbers to remember. Each pair has two trials, and one correct answer is required in order to proceed to the next level. In Digits Forwards the examiner reads a number sequence, and the task is to recall numbers in the same order (Lezak, 2012). This tests ability to attend to and register the presented stimuli, and reflects attentional capacity (Anderson et al., 2001). Contradictory in Digits Backwards instructions are to repeat numbers backwards, which tests the ability to hold information in memory and manipulate it (Anderson et al., 2001). Points are given when participant repeats the whole digit span correctly (Lezak, 2012).

Psychomotor tasks.

Hand dynamometer. Hydraulic hand dynamometer from *Baseline evaluation instruments* measured grip strength. Baseline’s hydraulic hand dynamometer has the same established validity and reliability for measuring grip strength as the instrument Jamar hand dynamometer (Virgil Mathiowetz et al., 1985; Virgil Mathiowetz, Wiemer, & Federman, 1986). Grip strength is considered a measure of general health (Häger-Ross & Rösblad, 2002; McQuiddy, Scheerer, Lavalley, McGrath, & Lin, 2015), human strength and as a screening test for motor function (Newman et al., 1984). The handle clamp of the dynamometer was adjusted to ensure a comfortable fit for each hand size. The participant became familiar with the instrument before testing, when provided trial and examiner demonstrated how to do a good gripping. In standing position, participant gripped the handle alongside the body. When ready, the participant was asked to squeeze with maximum force. Grip strength measurements in kilograms indicted by a needle's position were registered. Grip strength was measured three times for each hand (six in total), and the maximum output indicator was re-set to zero between tests. Mean scores were calculated for each hand. Fatigue effects were prevented by using a two-minute rest between the trials (Lezak, 2012) (Fabrication enterprises incorporated).

The Purdue Pegboard Test. The Purdue Pegboard Test (Tiffin, 1968) measures motor function of the upper extremities of the body, and assesses both manual dexterity and bimanual coordination. Two types of dexterity are measured: gross movements performed by arms, hands and fingers; and fine movements of fingertips. Equipment includes a board with vertically holes and three different sorts of metal pegs sorted in cups at the top of the board. Four different conditions were administered derived from the Purdue Pegboard Test, each following a fixed period timed by a digital stopwatch. The examiner gave a thorough instruction and demonstration of the various tasks before each condition, and sufficient practice trials were given to ensure everyone could meet requirements of tasks. The first three conditions lasted in 30 seconds each, using only pins. First task involved placing as many pins as possible with the preferred (dominant) hand alongside the same side of the board, afterwards in the second condition with the other hand and other board side. Each correctly placed peg earned one score each. In the third task, both hands working together were tested. Instructions was to simultaneously pick up a pin with the right hand and another with the left hand and thereby placing them coordinated down the rows; and to continue the process to the time was up. The score was the number of complete pairs. In the fourth condition, the participant got one minute to make as many assemblies as possible, in the specific order pin-washer-collar-washer. Instructions was to follow an alternating procedure using both hands all the time, but every other. Only completed assemblies consisting of four pegs got points (*Instructions and normative data: Purdue Pegboard model 32020*; Lezak, 2012).

Respiratory analysis instruments. Phonatory Aerodynamic System (PAS) model 6600 (KayPENTAXa, 2006) was used for respiratory analysis, measuring lung function, non-speech breathing during response time and speech-breathing and oral speech production in verbal tasks. PAS consists of hardware and software system for PC, and captures aerodynamic data (for instance pitch, sound pressure, airflow and air pressure) and provide data for respiratory analysis (KayPENTAXa, 2006). PAS includes the apparatus spirometer, KayPENTAXa (2006), a connected breathing mask, a microphone and hardware and software system. PAS ensures the measurement and evaluation of inspiratory and expiratory airflow (duration, peak and volume) as a function of time. In addition, the same instrument allows the evaluation of Vital Capacity. A 1.0 liter syringe calibrated the spirometer before each testing and ensured accuracy (KayPENTAXa, 2006).

Vital Capacity. VC was measured following standard procedures, and participants were instructed to perform a forced VC maneuver. The FVC maneuver involved inhaling as much amounts of air as possible, then holding breath while placing the breathing mask over nose and mouth and thereafter expire as fast and hard as possible in the mask. PAS provided three different measurements that reflects different aspects of VC. 1) Expiratory airflow duration: Measurement of exhalation`s duration in seconds. 2) Peak expiratory airflow: Maximal exhalation airflow in liters per second. 3) Expiratory volume: Total airflow volume in liters, measures amount of air in lungs (KayPENTAXa, 2006).

Inspiratory parameters during response time. Inspiratory breathing parameters during response time on the verbal tasks were assessed, by marking off airflow before articulation of the first word in each task (Figure 1.). PAS provided three different measurements for inspiratory breathing during response time in verbal tasks 1) Inspiratory airflow duration: Measurement of inspiration`s duration in seconds 2) Peak inspiratory airflow: Maximal inspiratory airflow in liters per second. 3) Inspiratory volume: Total inspiratory airflow volume in liters, measures amount of inhalation.

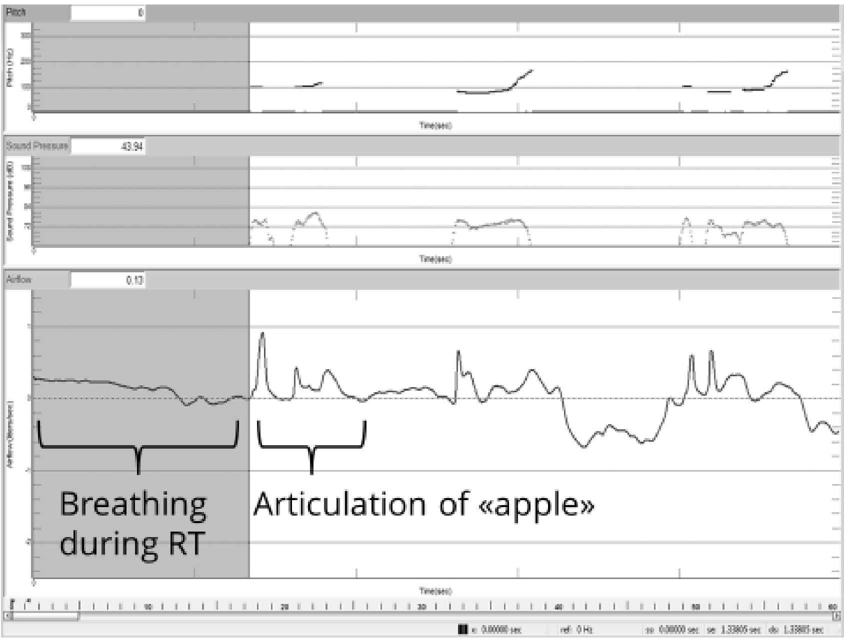

Figure 1. Illustration of data analysis of breathing parameters during response time on semantic fluency task in PAS before articulation of the Norwegian word “eple” (apple).

Spectrographic instruments for measurement of RTs. Computerized Speech Lab (CSL) model 4500 was used for spectrographic analyses to measure exact response times to verbal responses in all verbal tasks. CSL software captures voice signals produced in verbal tasks, and produces a sound wave that can be visually examined to obtain informations like real-time pitch, spectrograms and RTs. CSL consist of both hardware and software system, and captures voice signals (KayPENTAXb, 2006). All speech recordings were inspected to determine scores in VFTs, by counting number of produced words, repeated words and errors. CSL was used to determine total reading duration in control task and to count errors.

CSL ensures objective and precise response time (Raphael, Borden, & Harris, 2011). RT was the interval in seconds between the presentation of the verbal task cue (end of beep-sound) and right before the beginning of the first word produced by the participant (See Figure 2). Irrelevant utterances, like wrong answers or hesitations (“eeeeeh”), are not taken into account and response time was only measured from start point to first correct answer. Both VFTs had two conditions each (like fruits and animals in semantic task), and from this an average mean performance (number of correct generated words in both condition) and average RT (RT from both conditions) was calculated.

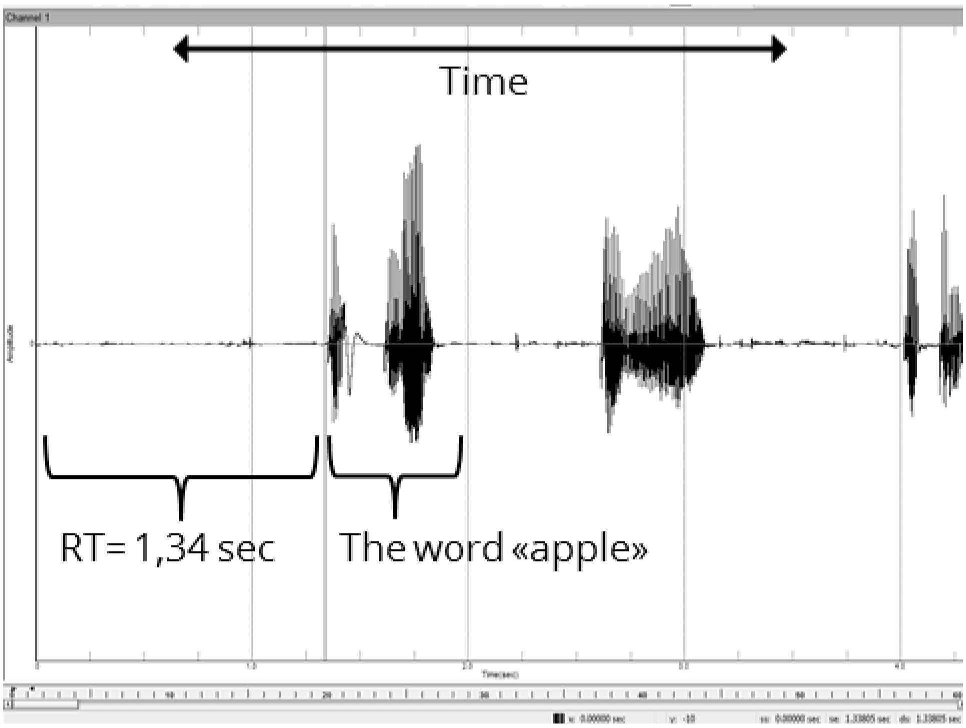

Figure 2. Illustration of spectrographic analysis of response time on semantic task using CSL 4500.

Verbal tasks. Verbal tasks included phonemic and semantic fluency task and a simple reading of a short text. The examiner gave thorough and identical instructions for all subjects before stimuli presentations, which also appeared at the monitor screen in front of the participant. Teenagers sat at approximately 60 cm from the screen. Examiner recorded with the PAS and CSL all responses and transcribed the recordings of the answers.

Oral phonemic verbal fluency. A Norwegian version of "Controlled Oral Word Association Test" (A. L. Benton, 1967) measured phonemic verbal fluency by the quantity of produced words. The test consisted of two word-naming trials, using the letters "F" and "S" presented separately. In each trial, the task was quickly to say as many words as possible that begun with the given appearing letter on the screen. Each trial lasted for 1 minute. The participants could not mention place names, proper nouns, repeat words, nor say variations of already mentioned words. Number of correct produced words, errors and repeats were both coded and analyzed. Final score equals the total number of correct generated words.

Oral semantic verbal fluency. A semantic task (A. L. Benton, 1967) assessed the processing component of working memory. Allotted one minute, the task is to produce as many words possible in a given category; but different words every time. The chosen categories were "animals" and "fruits and vegetables". Similar to phonemic fluency test all generated words both coded and analyzed before determining final score in each condition.

Reading a short text. Task involved reading a presented short text as fast and clear as possible without skipping any words. The text was the second story from “Logical memory I” from WMS-III (Wechsler, 2008) and was different from the story used earlier to evaluate immediate and differed memory. Reading mistakes were accounted, which expressed the level of accuracy in reading. Reading duration of the whole text in seconds was registered.

Procedure

Examination took place in a quiet room at the Department of psychology, were all participants were tested individually. A short interview gathered demographic data and health status. Testing took place in two sessions, and in between there was a 10-minute break. The first session lasted about 1 hour, and included the initial interview; cognitive tests: MMSE, BDI, Logical memory 1 and 2, Stroop test, Vocabulary, Digits span; and psychomotor tests: grip strength test and the Purdue Pegboard Test. The second session was a 30 minutes respiratory analysis, including a separate test of lung function (VC) and measuring inspiratory breathing during response time at the same time as executing verbal tasks. Participants wore a facemask connected to the Phonatory Aerodynamic System while talking in response to verbal tasks (se Figure 3). The verbal tasks were presented by the software E-prime on a computer screen in front of the participants. Both an oral and written instruction were provided before every verbal tasks. Participants were holding the handle of spirometer`s handle with two hands, while pressing breathing mask against the face; providing a closed vacuum in which air breathed is carefully monitored. Phonemic and semantic fluency tasks lasted 1 minute for each condition and the reading task was dependent upon participant`s reading speed. Each verbal cue started with a beep-signal, which allowed measuring precise response time. Each participant got an ID-number ensuring anonymity regarding personal information. Written consents were kept in a different storing.

Figure 3. Illustration of testing scene.

Respiratory analyses. Lung function was evaluated, with three measurements reflecting Vital Capacity: duration, peak and volume for expiratory airflow. In all verbal tasks, inspiratory breathing parameters during response time were collected. PAS measured volume, peak and duration for each inspiration during RT to all verbal tasks. A mean was calculated for each inspiratory parameter (volume, peak and duration) in all verbal tasks (phonemic VFT, semantic VFT and reading task). For instance, mean for inspiratory volume in the phonemic VFT was calculated by the average of values in inspiratory volume from the two phonemic conditions F" and "S".

Statistical analyses. Statistical analyses were performed with SPSS version 24 (SPSS Inc., Illinois, USA). In order to determine group differences between genders, independent t-tests were used on demographic variables. Multivariate analyses of variance (MANOVAs) were conducted to test group differences between genders on lung capacity (VC), neuropsychological variables (test battery), response times on three verbal tasks (two verbal fluency tasks and one reading task) and in inspiratory measures during RT on verbal tasks. Since t-tests are inadequate to control for intra-individual variability when there several dependent variables exist for each participant, MANOVA was selected as statistical method to examine contrasts between genders across performances on several dependent variables (Dancey & Reidy, 2014).

In order to evaluate associations between lung functions and cognitive parameters, two Pearson's correlational analysis were conducted on the whole sample: The first tested bivariate correlations between lung capacity (via VC) and performances on neuropsychological variables (test battery). The second tested bivariate correlations between inspiratory breathing measures during RT on the three verbal tasks and performance in the same verbal tasks measured in terms of correct number of answers. Due to the limited number of participants, we decided to conduct correlational analyses for the whole sample and not by gender, as it could have been the case with a high number of participants.

Results

Group differences

Demographic variables and BDI scores are presented in Table 1. Results showed no significant group differences between boys (*n* = 23) and girls (*n* = 26) concerning age, education or BDI scores. Genders were at the same age, *t* (47) = 0.75, *p* = NS, boys with an average age of 16.7 years (*SD* = 0.82) and 16.54 years for girls (*SD* = 0.65). There were no group differences in years of formal education (*t* (47) = 0.67, *p* = NS) or on Beck Depression Inventory performance (t (47) = -0.99, *p* = NS.

Table 1

Demographic variables and performance on BDI

	Males (*n* = 23) *M* (*SD*)	Females (*n* = 26) *M* (*SD*)	*t*(47)	*p*
Age	16.70 (0.82)	16.54 (0.65)	0.75	.46
Years education	10.93 (0.84)	10.79 (0.68)	0.67	.51
BDI	5.04 (2.77)	5.88 (3.17)	-0.99	.33

Note. BDI = Beck Depression Inventory; *M* = mean; *SD* = standard deviation

Lung function (Vital Capacity). Results for all three measures of lung capacity (VC) in boys and girls are presented in Table 2. Genders were equal in expiratory airflow duration (*F*(1, 47) = 0.03, p = NS). Genders differed significantly in peak of expiratory airflow, *F*(1, 47) = 4.34, p < .05, with boys (*M* = 6.54) scoring higher than females (*M* = 4.34). Expiratory volume was also significantly different between genders, *F*(1, 47) = 21.64, p < .001. Boys (*M* = 4.95) had significantly more expiratory volume compared to girls (*M* = 3.34).

Table 2

Gender differences in Vital Capacity

Vital Capacity	Males (*n* = 23) *M* (*SD*)	Females (*n* = 26) *M* (*SD*)	*F* (1, 47)	*p*
Airflow duration	3.30 (2.36)	3.41 (2.29)	0.03	.86
Peak airflow	6.54 (4.06)	4.34 (3.34)	4.34	**.04***
Expiratory volume	4.95 (1.36)	3.34 (1.07)	21.64	**.00*****

Note. Characters in bold denote significant correlations. *SD*= standard deviation,* $p < .05$. *** $p < .001$.

Neuropsychological tests. Table 3 summarizes test performance by gender in neuropsychological variables (test battery). A main effect of group was found, showing that boys and girls were significantly different when considering all the dependent variables Pillai's V = .809, $F(24, 23)$, $p = .001$. Univariate tests demonstrated that overall there were six specific tasks where gender differences were significant. First, group differences were observed on MMSE performance ($F(1, 46)= 4.84$, $p = .03$), in which boys ($M = 29.41$) demonstrated approximately one point advantage above girls ($M = 28.54$). There was a significant effect of gender in number of produced words in the phonemic fluency task ($F(1, 46) = 7.31$, $p = .01$, with females ($M = 13.94$) generating significantly more words than males ($M = 11.23$). Scores on two subtests of the Purdue Pegboard Test differed between genders, including the right-hand task ($F(1, 46) = 11.77$, $p = .001$) and the both-hands task ($F(1, 46) = 15.82$, $p < .0001$. For these subtests, females scored significantly higher compared to men in right-hand task (females $M = 15.81$, males $M = 13.91$) and both-hands task (females $M = 11.81$, males $M = 9.95$). Genders differed significantly in grip strength for both right hand strength ($F(1, 46)= 86.41$, $p < .0001$), and left hand strength ($F(1, 46)= 89.16$, $p < .0001$). Boys had higher grip strength compared to girls, both for right hand (males $M = 43.62$ kg, females $M = 29.29$ kg) and left hand (males $M = 40.42$ kg, females $M = 26.64$ kg). Genders did not differ in any of the other variables.

Table 3

Gender differences in neuropsychological tests

Tests	Males (*n* = 22) *M* (*SD*)		Females (*n* = 26) *M* (*SD*)		*F* (1, 46)	*p*
MMSE	29.41	(1.22)	28.54	(1.48)	4.84	**.03***
BDI	4.82	(2.61)	5.88	(3.17)	1.58	.22
Vocabulary	39.18	(8.91)	35.73	(8.87)	1.8	.19
Digits Span Forward	7.82	(1.59)	7.81	(1.63)	0.00	.98
Digits Span Backward	6.32	(1.99)	6.54	(1.30)	0.21	.65
Logical memory 1	13.77	(3.65)	14.19	(3.88)	0.15	.70
Logical memory 2	15.18	(4.46)	15.46	(4.43)	0.05	.83
Stroop test						
Words/45 sec	88.55	(13.25)	94.88	(13.03)	3.27	.08
Color/45 sec	65.73	(11.14)	70.69	(11.03)	2.39	.13
Interference/45 sec	45.18	(8.76)	46.46	(8.55)	0.26	.61
Phonemic fluency task						
Number of produced words	11.23	(2.86)	13.94	(2.90)	7.31	**.01****
Number of repeated words	0.14	(0.28)	0.23	(0.32)	1.16	.29
Errors	0.16	(0.24)	0.25	(0.59)	0.46	.50
Semantic fluency task						
Number of produced words	17.64	(3.73)	19.90	(3.47)	3.56	.07
Number of repeated words	0.16	(0.28)	0.25	(0.45)	0.66	.42
Errors	0.11	(0.26)	0.04	(0.14)	1.61	.21
Reading task						
Duration/sec	30.24	(5.54)	28.29	(5.08)	1.62	.21
Errors	2.09	(2.41)	1.31	(2.59)	1.81	.19
Purdue Pegboard						
Right hand/30 sec	13.91	(1.95)	15.81	(1.88)	11.77	**.001*****
Left hand/30 sec	13.09	(1.82)	14.15	(1.05)	3.54	.07
Both hands/30 sec	9.95	(1.73)	11.81	(1.50)	15.82	**.0001*****
Assembly/60 sec	7.5	(1.44)	8.23	(1.39)	3.18	.08
Hand dynamometer						
Right	43.62	(4.86)	29.29	(4.68)	86.41	**.0001*****
Left	40.42	(5.46)	26.64	(5.66)	89.16	**.0001*****

Note. Characters in bold denote significant correlations. BDI= Beck Depression Inventory; MMSE= Mini-Mental State Examination Test; *SD*= standard deviation,* $p < .05$. ** $p < .01$. *** $p < .001$.

Response time on verbal tasks. Response time (sec) on the three verbal tasks are presented in Table 4 by gender, showing that there was no significant difference in RT-performances, Pillai's V= .112, F(3, 44) = .112, p = .15, partial η^2= .11. Univariate analyses showed no gender differences, when considering variables after Bonferroni correction at α = .02. The p-vale in RT on phonemic fluency task did not reach significance, but it was demonstrated a trend towards it (p =.029), with faster RTs observed in females (M = 1.25) compared to men (M = 1.81).

Table 4

Gender differences in response time on verbal tasks

Response time (sec)	Males (*n* = 22) *M* (*SD*)	Females (*n* = 26) *M* (*SD*)	*F* (1, 46)	*p*
Phonemic	1.81 (1.11)	1.25 (0.57)	5.07	.03
Semantic	1.86 (0.72)	1.59 (0.77)	1.54	.22
Text	0.83 (0.53)	0.79 (0.50)	0.08	.79

Note. *SD* = standard deviation. * significant *p*-value corrected with Bonferroni = .02.

Inspiratory breathing during response time. Group differences in the three inspiratory airflow measures (duration, peak and volume) during response time (sec) on verbal tasks are presented in Table 5. There was no significant difference between males and females when considering all variables, Pillai's V= .265, F(9, 27), p = .24, partial η^2 = .26. Univariate analyses showed that there was a significant difference between genders on inspiratory volume during response time on phonemic fluency task, F(1, 42) = 12.58, p = .001, partial η^2 = .23, with males (M = -.57) scoring higher than females (M = -.30). For these values we protected the p-value with Bonferroni correction (α = .005).

Table 5

Gender differences in inspiratory airflow measures during response time on verbal tasks

Inspiratory measures with RT	Males (n = 20) M (SD)		Females (n = 24) M (SD)		F (1, 42)	p
Phonemic fluency task						
Duration (sec)	1.05	(0.47)	0.73	(0.35)	6.40	.02
Peak (liters/sec)	-0.92	(0.46)	-0.67	(0.33)	4.64	.04
Volume (liters)	-0.57	(0.32)	-0.30	(0.18)	12.58	**.001***
Semantic fluency task						
Duration (sec)	1.05	(0.52)	0.90	(0.42)	1.2	.28
Peak (liters/sec)	-1.01	(0.58)	-0.84	(0.45)	1.09	.30
Volume (liters)	-0.69	(0.58)	-0.46	(0.29)	3.09	.09
Reading task						
Duration (sec)	0.50	(0.42)	0.45	(0.31)	0.20	.66
Peak (liters/sec)	-0.98	(0.57)	-0.92	(0.46)	0.14	.71
Volume (liters)	-0.33	(0.32)	-0.25	(0.15)	1.00	.32

Note. Characters in bold denote significant correlations. RT= response time; *SD*= standard deviation. * significant *p*-value corrected with Bonferroni = .005.

Correlations

Lung capacity (VC) and cognition (test battery). Correlations between lung capacity (VC measures duration, peak and volume) and performance on neuropsychological variables (test battery) are presented in Table 6. Results showed restricted significant correlations between VC and scores from the battery test. It was found that right hand performance in the Purdue Pegboard Test was significantly related to duration of expiratory airflow (r = -.34, p < .05) and expiratory volume (r = -.32, p < .05). As expected, grip strength were highly correlated with expiratory volume (right hand, r = .73, p < .01; left hand, r = .71, p < .01). An unexpected result concerns scores obtained on the Logical memory 2 test, which was highly correlated with peak of expiratory airflow, r = .42, p < .01. Another unexpected finding was found between errors produced in semantic fluency task and duration of expiratory airflow, r = .29, p < .05.

Table 6

Pearson correlations between Vital Capacity and neuropsychological function

Tests	Vital Capacity Duration (sec)	Vital Capacity Peak (liters/sec)	Vital Capacity Volume (liters)
MMSE	.23	-.18	.17
BDI	-.20	.13	-.18
Vocabulary	.23	-.19	.05
Digit Span Forward	-.04	.00	.07
Digit span Backward	.17	-.15	.01
Logical memory 1	.23	-.16	-.06
Logical memory 2	-.24	**.42****	.10
Stroop test			
Words/45 sec	-.07	-.02	-.05
Colors/45 sec	.05	-.12	-.12
Interference/45 sec	.04	-.11	-.07
Phonemic fluency task			
Number of produced words	-.08	.05	-.26
Number of repeated words	.01	-.09	-.26
Errors	**.29***	-.27	-.09
Semantic fluency task			
Number of produced words	.17	-.11	-.09
Number of repeated words	-.01	.03	-.03
Errors	-.07	-.02	-.07
Reading text			
Duration/sec	.03	.02	-.08
Errors	.08	-.11	-.02
Purdue Pegboard			
Right hand/30 sec	**-.34***	.03	**-.32***
Left hand/30 sec	-.19	-.11	-.09
Both hands/30 sec	-.24	-.02	-.25
Assembly/60 sec	-.12	-.05	.00
Hand dynamometer			
Right	.06	.26	**.73****
Left	.05	.23	**.71****

Note. $N = 49$. Characters in bold denote significant correlations. BDI= Beck Depression Inventory; MMSE= Mini-Mental State Examination Test, * $p < .05$. ** $p < .01$, two-tailed.

Response time and verbal fluency. Correlations between performance on verbal abilities (VFTs and reading task) and response time are presented in Table 7. Higher scores in phonemic fluency (generating many correct phonemic words) were significantly related to shorter RT duration in same task, *r* = -.37, *p* < .01. Higher scores in semantic fluency (generating many correct semantic words), were significantly related to shorter response time to same task *r* = -.29, *p* < .05. Results showed no significant correlations between reading speed in the control task and response time in the same task, *r* = .22, *p* > .05. There was no significant correlations between response time, and repeated words or errors on the verbal tasks.

Table 7

Pearson correlations for verbal ability and response time

	Response time/sec		
Verbal ability	Phonemic	Semantic	Text
Phonemic fluency task			
Number of produced words	**-.37****	-.22	.02
Number of repeated words	-.16	-.08	-.01
Errors	.23	-.04	-.21
Semantic fluency task			
Number of produced words	-.09	**-.29***	-.24
Number of repeated words	.03	-.12	.05
Errors	-.06	-.09	-.12
Reading task			
Duration/sec	.01	-.02	.22
Errors	-.14	.13	-.02

Note. Characters in bold denote significant correlations. * *p* < .05. ** *p* < .01, two-tailed.

Verbal fluency, response time and inspiratory measures. Correlations between performances on the three verbal tasks, response time for the first word uttered in each verbal tasks, and inspiratory breathing measures (duration, peak and volume) during the same response time are presented separately for each verbal condition in Table.8, Table.9 and Table.10.

Results of phonemic fluency test performance, response time on phonemic task and inspiratory breathing during the same response time are presented in Table 8. Higher scores in generating phonemic words were significantly related to lower inspiratory peaks, *r* = -.31, *p* < .05. Response time on phonemic task were highly correlated with duration of inspiratory airflow during the same response time, *r* = .74, *p* = .01. Unexpectedly, repeating more words were significantly correlated with shorter duration of inspiratory airflow, *r* = -.29, *p* < .05. As expected, shorter response time duration on phonemic fluency task was significantly associated with less inspiratory volume, $r = -.39$, $p < .01$.

Table 8

Pearson correlations between phonemic verbal fluency, response time and inspiratory measures

		Inspiratory airflow	
	Duration (sec)	Peak (liters/sec)	Volume (liters)
Phonemic verbal fluency			
Number of produced words	-.22	**-.31***	-.06
Number of repeated words	**-.29***	.05	.22
Errors	.08	-.17	-.04
RT first phonemic word/sec	**.74****	-.06	**-.39****

Note. *N* = 49. Characters in bold denote significant correlations. RT= response time.

[a]Inspiratory airflow was measured during response time on phonemic task.

* $p < .05$. ** $p < .01$, two-tailed.

Correlations for semantic fluency test are presented in Table 9. As observed in the previous set of correlations, higher scores in semantic word generation were significantly correlated with lower inspiratory airflow peak, $r = -.35$, $p < .05$. Response time on semantic task were highly correlated with duration of inspiratory airflow during the same response time, $r = .74$, $p = .01$. Response time on semantic fluency task was as expected, significantly correlated with having less inspiratory volume during the same response time, $r = -.32$, $p < .05$.

Table 9

Pearson correlations between semantic verbal fluency, response time and inspiratory measures

	Inspiratory airflow		
	Duration (sec)	Peak (liters/sec)	Volume (liters)
Semantic verbal fluency			
Number of produced words	-.20	**-.35***	-.01
Number of repeated words	-.10	.15	.06
Errors	-.02	.19	.12
RT first semantic word/sec	**.74****	-.11	**-.32***

Note. *N* = 49. Characters in bold denote significant correlations. RT= response time.

[a]Inspiratory airflow was measured during response time on semantic task.

* $p < .05$. ** $p < .01$, two-tailed.

Correlational results from control task are presented in Table 10. Longer reading duration was significantly correlated with duration of inspiratory airflow during response time on the same task, $r = .31$, $p < .05$. Shorter RTs on reading task was highly correlated with shorter duration of inspiratory airflow during the same response time, $r = -.67$, $p < .01$. Faster RTs on reading task were correlated with having less inspiratory volume during the same response time, $r = -.37$, $p < .01$.

Table 10

Pearson correlations between reading speed, response time and inspiratory measurers

	Inspiratory airflow		
	Duration (sec)	Peak (liters/sec)	Volume (liters/sec)
Reading performance			
Duration/sec	**.31***	.26	-.08
Errors	.18	.11	-.09
RT first word in text (sec)	**-.67****	.28	**-.37***

Note. *N* = 48. Characters in bold denote significant correlations. RT= response time.

[a]Inspiratory airflow was measured during response time on reading task.

* $p < .05$. ** $p < .01$, two-tailed.

Discussion

The present study aimed to evaluate the association between lung function and cognitive functions among healthy adolescents, and to examine the role of gender in this relationship. In order to investigate the lung-cognition relationship, we measured teenager's performances on neuropsychological tests (test battery) and measures of Vital Capacity separately. A novel approach to address the relationship was conducted by measuring cognition (VFTs) and lung function (inspiratory airflow measures) at the same time. In order to answer the aims of the study and its hypotheses, separate sections will discuss in detail all significant results and main findings for each of the points in question.

Group comparisons by gender

Background variables. No difference existed between boys and girls concerning background variables, which is not surprising due to the restricted age range selected for the study. However, it is worth mentioning the exclusion of 11 participants due to high scores in the BDI. As it is well-known in the literature, depressive symptoms increase during adolescence (Kail & Steinberg, 1991), especially among girls. As reported by several researchers (Marcotte, Alain, & Gosselin, 1999; Ristic & Rancic, 2014) gender differences in depression among healthy adolescents show that girls have significantly higher BDI-scores than boys and that they often report more depressive symptoms compared to boys. Since the purpose of this study was to investigate the lung-cognition association among healthy teenagers we had to exclude these participants. Nevertheless, it is not uncommon to find depressive symptoms in teenagers (Steinberg & Lerner, 2009). For instance Ristic and Rancic (2014) found that 59.5 % out of over 400 teenagers had BDI-scores above 9. For this reason, it would be fruitful that future investigations study the association between lung function and cognition in depressed adolescents. In the present study 12 participants had scores that ranged from mild to major depression.

Cognitive functions (test battery). Data from the comparisons of genders regarding cognitive function showed that indeed there were no huge differences between boys and girls in cognition. Small gender differences were found in performance on phonemic fluency test, and surprisingly in MMSE. Highly significant differences between boys and girls were found in the psychomotor tasks, Purdue Pegboard Test and in grip strength.

MMSE. Unexpectedly, boys demonstrated better performance on MMSE by approximately one point more compared to girls. MMSE-scores are affected both by age and educational level (Crum, Anthony, Bassett, & Folstein, 1993; Tsantali, Economidis, Rigopoulou, & Porpodas, 2012), but in our study boys and girls were significantly equal in these variables. As explained in the method section, MMSE is mostly used to assess cognitive functioning in older adults for the detection of dementia, therefore studies examining teenager’s performance on MMSE and thereby gender differences as well, are very rare. Notwithstanding, some researchers have employed MMSE to evaluate younger individuals ranging from 3 to 19 years olds (Ouvrier, Goldsmith, Ouvrier, & Williams, 1993; Shoji et al., 2002; Tsantali et al., 2012).

Tsantali et al. (2012) provides scores on MMSE from several age groups (age range: 7-90); and results from 93 teenagers with the same age range as in our study from 16 to 18 years old, *M* = 29.2 (*SD* = 0.9). Tsantali et al. (2012) did not find gender differences, but found that the teenaged group demonstrated the smallest variance in the sample. It is roughly apparent that variances from our study, both in females (*SD* = 1.48) and males (*SD* = 1.22) are larger than in the study of Tsantali et al. (2012). Looking closer at our data, four of the female participants (one scored 25 and the others 26) demonstrated very low performances on MMSE and this might be an explanation for the gender difference we found in our study, since small sample sizes are sensitive to deviant scores. Females average MMSE-scores in our study (*M* = 28.54) is similar to the scores of 13-15 year olds (*n* = 80, *M* = 28.7) in the study of Tsantali et al. (2012). This comparison should be interpreted with caution, since Tsantali et al. (2012) sample sizes was nearly twice as big than in our study. MMSE is sometimes used to evaluate higher mental function in children and adolescents, and low MMSE scores in adolescents could be an indication of learning disabilities (Ouvrier et al., 1993). Meanwhile, none of girls with low scores reported having any learning disabilities in the initial interview when background information was collected. Alternatively, we think that lower scores in MMSE can also been interpreted as a result of stress, shyness or low motivation since many of the items and questions of this tests can probably be perceived as childish for adolescents.

Girls generates more phonemic words. A small gender difference favoring girls was found in phonemic fluency test, whereby girls significantly generated more phonemic words compared to boys. This confirms the hypothesis that girls might perform better in phonemic fluency tasks. Consistent with findings observed in female adults (Heister, 1982; Weiss et al., 2003a), in which women are better in generating phonemic words compared to men; girls in our study significantly generated more phonemic words than the boys did. As pointed out earlier, girls reaches performance peak in phonemic fluency earlier than boys (Porter et al., 2011), which might explain why they generate more phonemic words. Average age of boys and girls in our study were equal, around 16 years old, which is the same age as peak performance in phonemic fluency matures (Porter et al., 2011).

Higher scores on Purdue Pegboard Test observed in girls. Girls demonstrated higher scores on the “right hand” and “both hands” conditions of the Purdue Pegboard Test compared to boys, indicating better fine finger dexterity and eye-hand coordination in girls.

This finding is consistent with earlier research that have reported that girls are faster than boys on The Purdue Pegboard Test, both in childhood and adolescence (Gardner & Broman, 1979; V. Mathiowetz, Rogers, Dowe-Keval, Donahoe, & Rennells, 1986; Sattler & Engelhardt, 1982), and also in adult females (Heaton, Miller, Taylor, & Grant, 2004; Peters, Servos, & Day, 1990; Schmidt, Oliveira, Rocha, & Abreu-Villaca, 2000; Tiffin, 1968; Tiffin & Asher, 1948). Having small fingers and thumb size is an advantage in the Purdue Pegboard Test, and opposite having large hands handicaps performance (Peters et al., 1990). Females often have smaller hand size, which might explain why they are faster than men in picking up and placing pegs (Peters et al., 1990). If we had measured the finger and thumb size of our participants and taken this into account in our analysis, the observed gender difference might have been explained better. Meanwhile, one study (Nicholson & Kimura, 1996) have found that females are faster than men in this task regardless of their finger size (Roivainen, 2011). In any case, this is an important finding favouring fine motor function in girls.

Grip strength. Grip strength was not one of the main focuses in this study, but the hand dynamometer test was used since it belonged to the test battery of the main project. As expected, the boys grip were stronger both in both hands compared to grip strength in the girls. This finding is consistent with normative data of grip strength across the life course from nearly 50 000 individuals (age range: 4-90) provided by Dodds et al. (2014). The study of Dodds et al. (2014) found that grip strength of children are similar until adolescence, after which boys begins to gain strength more rapidly to a higher peak. Another study (Häger - Ross & Rösblad, 2002) that examined children's grip strength also showed that genders strength are similar until 10 years of age, after which boys are significantly stronger than girls. Weight, height and hand size are all variables that significantly affects grip strength (Häger - Ross & Rösblad, 2002), and this might explain why adolescent boys with their often bigger body size are stronger than girls.

Response time. There was no significant differences between genders in their response time on the verbal tasks, suggesting that genders speed to initiate on verbal tasks were equal regardless of type of VFT or difficulty degree. We failed to confirm our hypothesis that girls would demonstrate faster processing speed on verbal tasks. This could be explained by sample size used in our study. Meanwhile, though the *p*-vale in RT on phonemic fluency task did not reach significance, it was demonstrated a trend towards it, in which females demonstrated faster responses compared to men. Roivainen (2011) propose that females have better reading and writing skills (Halpern, 2000; Mikk & Lynn, 2009), and that for these reasons they might have advantages in speeded tasks involving numbers as in digits tasks or letters like in the phonemic task.

Vital Capacity. We expected to find better VC and greater inspiratory airflow measures in boys because of their bigger body size and height compared to girls. As expected, boy's respiratory values were significantly greater than the girls' values for the two VC measures peak expiratory airflow and expiratory volume. Males are often both larger and stronger than females, which might explain why they demonstrates better VC. Our finding is consistent with earlier research (Hoit, Hixon, Watson, & Morgan, 1990; Weinrich, Brehm, Knudsen, McBride, & Hughes, 2012), that also have reported higher lung capacity in boys versus girls during childhood and adolescence. Weinrich et al. (2012) provides normative data of VC in 14-17 years old measured by KayPENTAX PAS Model 6600 (same instrumentation as in our study), and have also found significant gender differences in expiratory volume and peak expiratory airflow. In children (age range: 7-11), greater performances are observed in boys on expiratory volume and peak expiratory airflow compared to girls (Pistelli et al., 1992). Meanwhile, Weinrich et al. (2012) discuss that such gender differences in VC are mostly found in older children. Related to this, muscle strength often increases more in boys during adolescence, which affects respiratory measures like FVC (Rosenthal et al., 1993).

Inspiratory breathing during RTs. Unexpectedly, there were mostly no significant gender differences for most of the inspiratory airflow measures during response time on verbal tasks. Only one inspiratory measure, inspiratory volume during RT on phonemic task, survived stringent Bonferroni correction. Boys demonstrated significantly more inspiratory volume during RT on phonemic task than girls, meaning that boys inhaled greater amounts of air during RT for this specific verbal task. This finding could be due to the bigger body size and physiology in boys versus girls. By our knowledge there is no research providing data for inspiratory airflow measures during response time in general or by gender. This make it difficult to interpret our observed gender differences in inspiratory volume during response time. Meanwhile, several studies have reported significantly greater in various airflow measures in males versus females in adulthood (Higgins & Saxman, 1991; Holmberg, Hillman, & Perkell, 1988; Wilson & Leeper, 1992; Zraick, Smith-Olinde, & Shotts, 2012). On the contrary, Weinrich et al. (2012) did not find any gender differences in expiratory airflow measures in teenagers (age range: 14-17).

Association between lung capacity (VC) and cognitive functions (test battery)

We examined correlations between separate performances on expiratory VC measures (duration, peak and volume) and on cognitive tests, which also included psychomotor tasks.

Due to low statistical power, we did not examine correlations by gender. We failed to confirm our hypothesis that lung function, measured via VC, is significantly correlated with cognitive functions. Results from the correlational analysis showed that most of the cognitive tests (expect Logical memory 2 and errors made in phonemic fluency test) were not significantly correlated with VC measures. Meanwhile, the psychomotor tasks Purdue Pegboard Test and grip strength, demonstrated significant correlations with VC-measures as expected.

Logical memory 2 and VC. An unexpected finding in the present study was that Logical memory 2 highly correlated with peak expiratory airflow (VC), indicating that high scores in delayed memory are associated with greater peaks in maximal exhalation of the VC manoeuvre. This finding is very interesting, but it is uncertain how these variables are associated. Thus, the finding can be incidental. However, it is known that oxygenation is important in memory processes (D. Benton, 1990; S. Craft et al., 2013; S. Craft et al., 1992; Manning et al., 1990; Scholey et al., 1998).

Errors in semantic fluency task and VC. Unexpectedly, generating more wrong answers- like mentioning a word not belonging in the given category, was weakly correlated with duration of expiratory airflow (VC). Given that the correlation was small, it is difficult to interpret how these variables are related, and it is possible that the finding is incidental.

Purdue Pegboard, grip strength and VC. As expected performance on the Purdue Pegboard task were highly correlated with Vital Capacity. This indicates that having better fine motor skills and eye-hand coordination is connected to an also better lung capacity. Grip strength in both hands were strongly correlated with Vital Capacity. This indicates that having stronger grip in both right and left hand in adolescence, is strongly correlated with having better lung capacity.

Association between inspiratory breathing during response time in verbal tasks and performance on verbal tasks

Correlations between response time and verbal fluency. First, we examined whether performance on verbal fluency tasks (verbal fluency) shared a significant relationship with response time to the same verbal tasks. Results revealed that teenagers who had higher number of correct produced words, both in phonemic and semantic, also responded faster in the same tasks. This confirms that appropriate performance of verbal fluency task is reflected by shorter initial time to respond. Interestingly, no significant results were found between reading performance and response time, which suggest that length in RTs is an important component of execution in complex verbal tasks like VFTs.

Association between inspiratory breathing and verbal fluency. Inspiratory airflow measures (duration, peak and volume) during response time on three verbal tasks (VFTs and reading task) were correlated with performance in the same verbal tasks in terms of number of correct produced words, repeated words and errors. Several significant correlations were found between inspiratory airflow measures and cognitive performance in verbal tasks, indicating presence of an association between lung function and cognition when both capacities are measured at the same time. Results demonstrated a trend in which greater inspiratory volume occurs in phonemic fluency task, which confirms our hypothesis that the phonemic task is more demanding for teenagers and therefore more inspiratory volume is needed. This point is further confirmed by the degree of the correlation which was higher between phonemic fluency and inspiratory volume, than between inspiratory volume and the semantic fluency. This finding could indicate that teenagers needs more oxygen to accomplish tasks that they experience to be difficult, like the phonemic fluency task. Phonemic fluency tasks are more difficult during adolescence, because EF is still developing and such tasks requires more of EF. In phonemic fluency tasks EF is needed when the participant is required to plan correct word utterances, inhibit errors and also keep attention focused (Martin, Wiggs, Lalonde, & Mack, 1994). Nevertheless, individuals in general, not just in adolescence, finds it more difficult to generate words by letters (phonemic), than words belonging to a semantic category (Diaz et al., 2004; Strauss et al., 2006).

Compared to its relation to phonemic fluency, inspiratory volume was to a smaller degree connected to semantic fluency. This indicates that teenager’s needs smaller amounts of oxygen when retrieving a semantic word compared to retrieval of a phonemic word, and also suggesting that this concrete task was less difficult. Related to this, teenagers generated more correct number of semantic words than phonemic words. Semantic retrieval relies more on automatic processes than phonemic retrieval, which might explain why oxygen usage and performance are different on these tasks. Retrieval of one semantic word often leads to automatic activation of closely related semantic words (Martin et al., 1994). Meanwhile, phonemic retrieval is less automatic and initiates more effort and complex searching strategies because words are organized in a less accessible manner in phonemic memory (Kremen et al., 2003).

Unexpectedly, inspiratory volume demonstrated a higher correlation with response time on reading task, than with response time on semantic fluency task. The reading task was considered to have low difficulty degree, it is therefore difficult to explain that oxygen usage in terms of inspiratory volume is higher on reading task than for semantic task. An explanation could be that more air is inhaled for text reading compared to single word production, because more air is needed for longer speeches than for single words. Compared to silent breathing that uses 10 % of lung capacity, normal speech requires 25 % of lung capacity (Raphael et al., 2011). Another possible explanation is that the teenagers experienced the task to be difficult, or being the last test executed from the battery – participants might have been more tired during performance on this task. Frequency information on number of mistakes made in verbal tasks, shows that teenagers had more errors in the reading task (*M* = 1.67, *SD* = 2.02) compared to phonemic (*M* = .20, *SD* = .46) and semantic fluency (*M* = .07, *SD* = .20*)* tasks.

Strengths and limitations

To our knowledge this is the first study that investigates the interrelationship between inspiratory airflow during response time on verbal tasks. Stronger correlations were found in the lung-cognition relationship, when both capacities were measured *at the same time*. This a clear strength of the study, that suggests that this method is a better way to evaluate the association than the more regular approach of measuring cognitive abilities and lung function separately.

On the other side, a limitation of our study was a small sample size (*N* = 49). The sample size allowed us to evaluate the lung-cognition relationship to some degree and we found small, but significant correlations in the interrelationship of lung-cognition. A larger sample size might have provided more distinct correlations in the association. Furthermore, the sample size in the study was too small to make comparisons between the genders in the association. Another limitation of the study is that we only examined a few cognitive functions measured by VFTs in the interrelationship between lung-cognition, such as executive aspects of language, executive search strategies of memory retrieval, planning of utterances, clustering ability, vocabulary knowledge and inhibition. It is possible that other types of cognitive tests are more related to lung function.

This study tested teenagers ranging from 16 to 18. Meanwhile, adolescence includes *all* the years between childhood and adulthood (Steinberg & Lerner, 2009). Several physical and psychological changes are happening during this span, and further research should also investigate the lung-cognition association in both earlier and late adolescent years. Maturation of EF proceeds well into early twenties, for instance a research study (Toga, Thompson, & Sowell, 2006) suggests that frontal lobe matures first between 20-30 years of age. The ideal would have been to do a longitudinal study, to better understand how cognitive and respiratory measures changes over the time.

Some further limitations exist related to testing of the participants, whereby the examination situation could to some degree affect the subject. For instance the participant`s breathing can be affected by the awareness of it being monitored, thereby causing respiratory changes that would not happen breathing naturally (Ley, 1999).

Inspiratory airflow measures connection to cognitive abilities needs further evaluation. Results of this study indicates a trend in healthy teenagers, whereby phonemic and semantic fluency requires different amounts of inspiratory airflow. This suggests that the various, underlying cognitive mechanisms have different oxygen usage during this life period. Measuring RTs is very time consuming, and therefore this study only examined RTs for the first word in each verbal task. More RTs are needed to better understand the role of inspiratory breathing on the verbal tasks applied in this study. In addition to inspiratory breathing during response time, it could also have been interesting to measure airflow measures during speech production or in-between words in the VFTs. During non-speech breathing, inhalation and exhalation duration is nearly the same. However, duration of inhalation in respiratory cycle is only 10 % during speech production (Denny, 2000).

Conclusion

This study confirms that phonemic VFTs are the verbal tasks with highest difficulty for the adolescents evaluated in the study. The reason probably is because executive functions are not still fully developed in late adolescence. Furthermore, the present study also confirmed that in general there are no gender differences in cognitive performance. However, it was interesting that among the few tasks showing gender difference the phonemic VFT was one of them, in which girls turned out to be better than boys. Results also showed that RTs are closely related with a good execution in phonemic and semantic VFT. Finally, the correlational analyses showed that inspiratory airflow measures are more important in the phonemic VFT compared to the semantic VFT. We therefore conclude that phonemic VFT is more sensitive upon respiratory mechanisms in late adolescence than semantic VFT is.
As a whole, this study confirms an association between inspiratory airflow parameters during response time on phonemic VFTs. Further research should investigate gender differences in this association since we only conducted correlations in the whole sample due to the limited sample size. Regarding correlational analyses of the association between cognitive functions from the test battery and Vital Capacity parameters, there was only a few significant correlations with cognition. Hence, our study shows that the methodological approach of measuring both lung function and cognition *at the same time* is a more adequate procedure to

assess the lung-cognition association than using the customary approach of correlations with separate measurements.

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