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Cognitive Reserve Potential: Assessing personal and situational determinants of lifetime cognitive trajectories

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To my parents,
my teachers,
my friends:

Thank You

Da te posso venire senza dover indossare maschere o recitare, senza dovere svendere neanche la più piccola parte del mio mondo interiore.

Con te non devo giustificarmi, non devo difendermi, non devo dare dimostrazioni…

Che farmene di un amico che mi giudica? Se invito uno zoppo alla mia tavola, lo prego di accomodarsi, non gli chiedo certo di danzare.

Antoine de Saint-Exupéry

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ABSTRACT

Cognitive Reserve is a theoretical construct elaborated to explain discrepancies between brain integrity and cognitive functioning. Indeed, high interindividual variability has been observed in the relationship between neural damage and its clinical and functional manifestation. Cognitive Reserve explains this variability in terms of efficiency and flexibility of brain processes: greater adaptability in the execution of cognitive tasks grants a better response to brain damage or ageing.

The development of Cognitive Reserve is influenced on the one hand by innate factors and on the other by experiences encountered throughout the lifespan: mainly education, work activity, and leisure activities. Because of this "cumulative" nature of Cognitive Reserve, in this dissertation, we emphasise the importance of investigating the factors that determine its development from a young age. Thus, we propose the concept of Cognitive Reserve Potential (CRP) to represent the set of functional resources available during adolescence, before educational and work experiences are concluded or even started.

In the first work presented here, we use data from a longitudinal birth cohort study to examine the impact of youth cognitive functioning in a longitudinal perspective. Our analysis relies on latent growth curve models to investigate the association between earlier (11-70 years) and later (70-82 years) cognitive change. We thus show for the first time how trajectories of cognitive change between childhood and late adulthood significantly predict decline over 12 subsequent years. This finding sheds light on the nature of cognitive ageing and lends additional relevance to early life experiences, the impact of which may reverberate across the lifespan into later life.

The second study aims to clarify the relationship between environmental and experiential factors and cognitive functioning in adolescence. In it, we analyse the complex system consisting of measures of crystallised intelligence, fluid intelligence, and indicators of several environmental dimensions, namely, socioeconomic status, home possessions, cultural capital, and reading habits. A network analysis shows that cultural capital and reading habits are associated with verbal abilities independently of socioeconomic status and possessions. Thus, this study confirms the importance of taking a more nuanced view than just socioeconomic status, when considering environmental and experiential factors in relation to cognitive development.

To address this need, in Study 3, we develop a questionnaire dedicated to the assessment of Cognitive Reserve Potential in adolescents, the CRPq. The instrument measures attitudes and habits pertaining to leisure activities, family environment, peer relations and eating habits. A principal component analysis, confirmed by a factor analysis performed on an independent sample, shows that the CRPq reliably measures 12 subscales while also providing a global CRP score. Thus, we

could perform an initial exploration of associations between CRP and measures of intelligence, executive functioning, and socioeconomic factors, which was also presented and discussed in Study 3.

Cognitive Reserve in youth is a complex phenomenon that has only recently begun to be studied. The present dissertation, therefore, represents an initial approach. In our concluding remarks, we reflect on the challenges encountered so far and on possible future perspectives.

I. INTRODUCTION

Lifetime cognitive change
and
the role of Cognitive Reserve

1.1. Trajectories of Lifetime Cognitive Change

Cognitive trajectories capture change in cognitive abilities across time. Understanding how intelligence develops during the lifespan and what factors can affect or be affected by these changes is fundamental to reconstruct the puzzle of human intellect in its entirety.

1.1.1. Cognitive Trajectories in Theories of Intelligence

The ways in which things change can tell us a lot about their nature and function. Observing and measuring change in cognitive abilities has been a stepping stone for the development of theories of intelligence: the time frame of growth and decline can help to identify underlying mechanisms or reveal potential causes.

1.1.1.1. The origins of the issue – early studies on the growth and decline of intelligence.

The study of intelligence as an individual characteristic is relatively recent. Throughout the 19^{th} century, intelligence, intended as an overall ability to think or reason, was discussed primarily as a distinctive human feature compared to animals, and investigated in the context of groups. It was only at the turn of the 20^{th} century that interest in individual mental capacity came to the forefront. Institutional and social changes, such as universal primary education and the diffusion of asylums, made individual differences in intelligence more evident and relevant in everyday life. At the same time, scientific methods were establishing themselves as privileged forms of explanation. Thus, across the late 19^{th} and early 20^{th} century, a number of investigators began to explore the meaning of individual differences in the overall level of intelligence (Carson, 2015).

These explorations led to the creation of the first individual intelligence assessment test by Alfred Binet and Théodore Simon in 1905 France. The Binet-Simon Intelligence Scale (Binet & Simon, 1905, 1916) was developed with the intent of screening children's mental abilities and identify those who lacked the necessary faculties to participate in public education. Following this first example, the use of intelligence tests spread quickly in Europe and America, and other tests were developed, such as the American adaptation of the Binet-Simon, the Stanford-Binet scale, in 1916 (Terman, 1916) or, later, the Wechsler Scales, which are still widespread today (e.g., Wechsler, 1998a). The WWI efforts brought along the first psychometric test designed for group administration, the Army Alpha (Clarence Stone Yoakum & Yerkes, 1920). The impact of these tests on intelligence research was ground-breaking, in many ways shaping the very concept of intelligence. For instance, the notions of *mental age* and *intelligence quotient (IQ)* were the terms used to report results in the Binet-Simon and in the Stanford-Binet scales, respectively.

One early instance of the application of psychometric tests to research on intelligence is the work carried out by Jones and Conrad in the 1930's using the Army Alpha (H. E. Jones & Conrad, 1933). This study well represents the status of intelligence research at the beginning of the 20th century, while some of the questions it dealt with still drive research efforts today. The main goal of the study was to reconstruct the curve of intelligence from childhood to late adulthood. In order to do it, the authors administered the Army Alpha forms 5 and 7 to a large (n = 1191) sample of Rural New England population between the ages of 10 and 60 years. The data they collected was used to investigate additional phaenomena, such as the age-related differences in individual task scores, and differential growth and decline according to intelligence level.

Jones and Conrad's data revealed that intelligence, represented by the total score on the Army Alpha test, rose almost linearly from age 10 to age 16 years. It then progressed more slowly and reached a peak between 18 and 21 years, on average. Afterwards, it declined at a rate that was much more gradual than the observed growth rate and around age 55 participants tended to score the same as 14-years-old. At the time, the age of mental maturity was a debated point. While it was evident that intelligence developed progressively during childhood, there was no agreement on the age at which such development could be considered complete, nor on what happened afterwards, whether intelligence reached a stable plateau or was subject to additional fluctuations. These results indicated that cognitive ability tended to be at its highest at the threshold between adolescence and early adulthood. On the other hand, they also confirmed that it was impossible to speak of a "mental age of adults", as intelligence continues to change with age even in adulthood – generally declining[1].

The above trajectory concerned the overall score on the test, but the authors detected important differences in the developmental curves of individual tasks, both in the age of peak performance and in decline rates (precipitous, or negligible). Specifically, tasks that could be considered of "basic intelligence" (e.g., analogies, common sense, numerical completion) had a different ageing pattern from tasks of "information" (i.e., vocabulary and general information). Basic intelligence presented a steeper developmental curve, with sharp growth and quick decline during adulthood, whereas performance based on the use of acquired information showed no decline after adolescence, effectively peaking in advanced maturity. Furthermore, the two types of tests contributed differently to the overall test score depending on age. At age 10, "information" tasks accounted for 25% of the total score, but in the oldest group of participants (age 50-60), they

[1] It is interesting to notice how much care the authors took in controlling for possible confounders of cognitive decline after age 21. Even a superficial comparison between this study from the 1930's and current literature, wherein a decline in general cognitive performance in adulthood is often expected, can give us an idea of the progress that has been made towards the definition of cognitive trajectories. These patterns have now been replicated so many times that they can be considered to represent the prototypical cognitive aging profile (Salthouse, 2010).

represented approximately 40% of the total score. This suggested that adults tend to rely more on accumulated information (in other words, on experiences) to fulfil intellectual requirements, as opposed to children who count more on abilities which allow to apply information to new situations. The existence of two main change patterns of cognitive abilities was observed consistently and repeatedly (H. E. Jones & Conrad, 1933). In the next section ("*Intelligence in modern psychometric theories*") we will describe how some of the main theories of intelligence accounted for it.

Is age kinder to the initially more able? (Owens, 1959) In other words: Are growth and decline rates associated with intelligence level? In their work, Jones and Conrad attempted to infer an answer to this critical question from the dispersion (in Standard Deviation units, SD) of test scores at different ages. For instance, they observed that the SD of the total score and of individual task scores all increased during adolescence. The difference between high and low performers increased with age, suggesting differential development rates. The picture was not so clear when considering decline rather than growth: The dispersion of scores increased over time for some tasks (e.g., 4 – "vocabulary"), decreased for others (e.g., 3 – "common sense") and remained stable for total Alpha, seemingly negating a clear differential decline. Section 1.4 and Study 1 are dedicated to the study of individual differences in cognitive ageing and will illustrate how modern research methods are employed to answer these questions.

1.1.1.2. Intelligence in modern psychometric theories.

Cattell's theory of fluid and crystallised intelligence.

Psychometric theories of intelligence developed concomitantly with the rise of intelligence testing. The intent of such theories is to define the characteristics of the object being measured., such as its structure and components. It is neither possible nor pertinent to relate a full account of the history of psychometric intelligence theories in this work (for an authoritative account, we refer to Kline, 1991). However, we will present one of the most influential among early modern theories of intelligence, which took directly into account the dynamic change of cognitive abilities through the lifespan: Cattell's gf-gc theory (Cattell, 1943).

Cattell's theory of intelligence derived from the psychometric measurement of abilities and he observed that, despite the fact that cognitive test scores were all positively correlated, it was possible to identify two distinct clusters: two subgroups of tests that correlated more strongly with each other than with tests from the other group. He thus identified two general factors of intelligence, which he termed *fluid* and *crystallised* (abbreviated in gf and gc, with a reference to Spearman's general factor *g*). Fluid ability was the purely general ability to discriminate and perceive relations, to solve problems in tasks where previous knowledge was uninformative, and it impacted performance on speeded or unfamiliar tasks. Crystallised ability, on the other hand, was acquired and consolidated knowledge, as well as the capacity to apply it successfully in any situation in which it may be relevant. These two groups of abilities were also characterized by different patterns of development and decline through the lifespan. The different timelines supported Cattell's view of the relationship between the two factors, which he described as distinct but not entirely independent of one another: The investment of fluid intelligence was required to build up skills and knowledge that, once consolidated, remained available in the form of crystallized intelligence.

Baltes' theory of Lifespan Cognitive Development.

The fluid and crystallized components of intelligence and their specific developmental trajectories played an instrumental role also in the definition of lifespan developmental psychology (Baltes, 1987). Baltes' theory placed a strong emphasis on how the interplay between biological and cultural factors shaped trajectories of cognitive development (Lindenberger, 2001), and Cattell's model of intelligence was integrated within this perspective. Baltes referred to fluid *mechanics* and crystallised *pragmatics* of intelligence (Baltes, 1987). The Mechanics captured basic organizational properties such as speed, accuracy, and coordination of cognitive processes. They were heavily dependent on genetics and on biological processes: Their development in infancy and childhood was seen as the result of maturation, whereas their decline was consistent with "brain-related consequences of less effective phylogenetic selection pressures operating during [late life]" (Lindenberger, 2001). The Pragmatics, on the other hand, reflected the declarative and procedural knowledge acquired through culture and socialization: They concerned the application of cognitive mechanics in specific contexts, to specific pieces of knowledge. Pragmatics became increasingly significant with age, as developmental tasks and external (social) expectations relied on the mastering of culturally relevant information and practices. Moreover, some kinds of knowledge, such as the life managing and planning abilities usually associated with wisdom, tended to increase with time, as exposure to a variety of life experiences accumulated. The multi-directionality of change in cognitive abilities, the fact that some skills declined while others improved, was also used by Baltes to construct his view of development as combination of gain and loss, as interplay between different cognitive systems (i.e., mechanics and pragmatics). He formulated the concept of "Selective optimization with compensation" (Baltes, 1987): As the availability of cognitive mechanics decreases with age, resources are channelled towards selected procedural and declarative knowledge systems, which can continue to function at optimal levels and are sometimes the basis of compensatory mechanisms.

1.1.1.3. Studying cognitive trajectories to clarify cognitive change mechanisms.

Currently, trajectories of change are still studied as an instrument to understand the processes and mechanisms that guide it. For instance, Salthouse (2014) compared older-life trajectories of several vocabulary tests, requiring different types of effort from respondents. The idea was that, as always, change in test scores would reflect change in the abilities involved. Additionally, Salthouse intended to break down the mechanisms of change that affect a relatively compact construct such as vocabulary knowledge. He observed that scores on tests relying on semantic representation declined sooner than scores on tests based on information retrieval – leading to the hypothesis that the former ability deteriorates sooner than the latter.

Above were some examples of how descriptive examination of change ties in with theory development about the underlying cognitive structures and the mechanisms that drive their development, maintenance, and decline. But what do we currently know about cognitive change? What is the “state of the art”?

1.1.2. Measuring Cognitive Change. Research Designs and Their Implications

Representing cognitive trajectories in a true-to-life manner, albeit at a descriptive level, is no mean feat. To achieve it, it has first been fundamental to understand the methods employed to study change, along with their assumptions and implications. Untangling the web of age-related processes can be daunting: Genetic and biological factors are at play, as well as individual experiences and choices, but so are large-scale cultural and societal phenomena that change through time and that shape the environment in which individuals live their lives. The study designs implemented to assess cognitive abilities and their development carry important implications that need to be carefully considered.

1.1.2.1. Cross-sectional and longitudinal research designs.

Two designs are mainly applied to the study of cognitive trajectories: cross-sectional designs and longitudinal designs. Cross-sectional designs collect data on a single occasion from participants of different ages. The trajectory of cognitive abilities is then estimated by comparing the results obtained by younger and older participants. Longitudinal designs collect data from the same group of participants at different ages, by assessing each person on multiple occasions over time. In this way, it is possible to measure change within-person as well as change in mean scores across the lifespan.

Each of these two methods presents unique perks and advantages, as well as sensitivity to specific confounders. Cross-sectional designs consist of a single assessment; therefore, the participants do not develop experience or familiarity with the tests used, and the practical execution is relatively simple, making it possible to recruit large and diverse samples. The main downside of such designs is that, while they are assessing potentially age-related individual differences, they are not measuring change in a strict sense: Each participant is tested on only one occasion, and there is virtually no information on his or her cognitive abilities prior to, or after, that occasion (i.e., no individual "baseline" or reference point). This is a relevant concern, particularly in the light of cohort effects: Influences on individual characteristics, including cognitive abilities, determined by shared life experiences – such as the type of social expectations, education, work opportunities, major historical events – that constitute the common environment for people born in a given time period. Possibly the most famous cohort effect within the field of Psychology is the Flynn effect (Flynn, 1984), the raise in mean scores on tests of cognitive abilities from one generation to the next. Cohort effects mean that the level of cognitive ability at a given age is not only a function of age, but also of environmental factors that, in the case of participants born 50, 30, or even 10 years apart, may be substantially different. For instance, the Flynn effect implies that, due to the progressive increase in cognitive test scores, the average scores of participants in their 70's are likely lower than the mean scores that would be obtained in 50 years' time by participants who are currently in their 20's. Comparing the cognitive performance of different cohorts without acknowledging this type of confounder may lead to an overestimation of age-related changes in cognitive abilities, as we attribute entirely to ageing effects that depend also on environmental factors (such as cohort-specific school system, quality of education, or familiarity with cognitive test-type tasks). Cross-sectional designs are particularly exposed to this type of confound because their structure makes it difficult to distinguish age effects from cohort effects.

By studying individuals from the same cohort (e.g., from the same birth year) over time, longitudinal designs can help to separate aging and cohort effects. Many longitudinal studies also recruit participants from several consecutive cohorts and assess each of them at specific ages, analysing the stability or variability of cognitive trajectories across generations (e.g., Small et al., 2011). These designs, too, present challenges due to their inherent features, mainly the need for repeated assessments. One such challenge is selective attrition: The fact that individuals who drop out of the study and individuals who complete it may differ on some relevant measure, resulting in a final sample that is not representative of the intended population. For instance, it has been observed that dropouts in longitudinal studies of cognitive skills had lower cognitive test scores at early assessments, compared to completers (e.g., Taylor et al., 2018). A second issue in longitudinal designs, particularly in those involving psychometric measures of cognitive ability, is the learning effect: participants who are repeatedly presented with the same or similar task may become familiar with the requirements, or develop strategies, leading to an improvement in scores over assessments. This is problematic because, with experience increasing as time passes, the effects of learning may confound or mask the effects of aging.

1.1.2.2. Cognitive change trajectories in cross-sectional and longitudinal designs.

Why is it so important to consider the implications of each study design? The Seattle Longitudinal Study (SLS, Schaie, 2013) offers an excellent example of the role played by the research methods in shaping a study’s results. The SLS is one of the longest-running and most extensive longitudinal studies of cognitive abilities and since its establishment, one of its aims was to resolve the discrepancies between cross-sectional and longitudinal findings regarding the development of adult cognitive abilities (Schaie & Willis, 2010). The study is structured around a cohort-sequential longitudinal design, examining cognitive and psychosocial change in multiple birth cohorts over the same chronological age span. This allows for longitudinal and cross-sectional measurement at the same time. The SLS has included participants from 22 to over 100 years of age.

A first fundamental finding of the SLS study was to confirm that there is no uniform pattern of age-related changes across all intellectual abilities, but indeed important ability-by-age and ability-by-cohort interactions complicate the picture of adult cognition. Six cognitive skills were taken in exam throughout: perceptual speed, inductive reasoning, spatial orientation, verbal memory, verbal ability, and numeric ability, and their lifespan change was assessed using both cross-sectional and longitudinal comparisons.

In data collected through a cross-sectional design the first four abilities showed trajectories usually associated with fluid intelligence: they peaked in the mid 20’s and declined almost linearly afterwards, across adulthood and older age. The other two skills investigated, instead, can be associated to crystallised intelligence: They kept improving well into adulthood, until the early 40’s, and remained relatively stable until the late 60’s, with small losses in later years.

When the same cognitive abilities were assessed longitudinally, administering the same tasks to participants multiple times over the years, only perceptual speed and verbal ability had trajectories similar to those derived from cross-sectional comparisons. The change pattern of inductive reasoning, spatial orientation, and verbal memory was characterized by greater stability and slower decline overall: scores on the tasks tapping on fluid ability continued to improve until mid-life, around age 50, instead of peaking in the mid-20’s, and exhibited only small declines afterward. Finally, numeric ability had an early plateau (between age 25 and age 60), followed by a linear decline.

We can thus recognize the issues mentioned above and associated with the two different study designs. Four of the six abilities studied (i.e., inductive reasoning, spatial orientation, verbal memory, and numeric ability) appear to have different trajectories depending on whether cross-sectional or longitudinal data are considered, and the differences would be compatible with either cohort effects (earlier cohorts having lower scores compared to later cohorts at the same age) or learning effects (the familiarity acquired through repeated testing staves off decline for a time, resulting in a plateau) or a combination of both.

1.1.2.3. The quasi-longitudinal research design.

Understanding the advantages and disadvantages of different study designs in the context of cognitive change has allowed researchers to minimize bias in the interpretation of results and to devise solutions for more accurate assessments of age-cognition relationships. For instance, a third type of design: the quasi-longitudinal, or cohort-sequential, design, which was first implemented by Schaie (1973). This design was developed in the effort to clarify the differences and discrepancies between cross-sectional and longitudinal methods. It consists in testing different members of the same birth cohorts at different points in time, i.e., at different ages. For instance, a group of people born in the same year may be tested when they are 20 years old, and a second group of people, born in the same year as the first one, may be assessed ten years later, when they are 30.

Quasi-longitudinal designs do not share all the advantages of the more common methods (e.g., they require a long time in order to assess participants from the same birth cohort at different ages, and they cannot capture actual individual change, because they are based on a single assessment per participant). In exchange, the data collected in quasi-longitudinal designs is free from cohort effects, because all participants belong to the same birth cohort, and it is free from learning effects, because each individual takes the tests only once. In sum, this type of design, while not sharing the same advantages of the cross-sectional or longitudinal designs, is none the less robust against their main weaknesses, and can thus represent an informative benchmark.

Quasi longitudinal designs are important because with their features, which sit at the intersection of cross-sectional and longitudinal designs, they offer an informative comparison to both. Comparing them to longitudinal data can give indications regarding the importance of learning effects, whereas comparing them to cross-sectional data may reveal the extent to which cohort effects confound the measurement of cognitive ability. In order to assess the relative impact of cohort and learning effects on cognitive performance, Salthouse (2019) used the quasi-longitudinal design as a comparison for both cross-sectional and longitudinal data. In Salthouse's work longitudinal data from three measurement occasions spanning approximately nine years was compared to cross- sectional and quasi-longitudinal data collected from age-matched participants.

In that study, longitudinal data exhibited the largest deviance from both cross-sectional and quasi longitudinal data, suggesting that learning effects were a relevant confounder, whereas the cohort effects were a much smaller one.

1.1.3. Trajectories of Domain-Specific Cognitive Change

The results gathered so far are still coherent with the early distinction between "fluid" abilities – innate abilities (or at least little affected by experience) associated with the elaboration of stimuli and the processing of new/previously unknown tasks – and "crystallised" abilities – acquired skills that are strongly shaped by experience and are associated with applying previously learnt information/strategies to current tasks. Abilities such as processing speed, inductive reasoning, "logical" memory, visuospatial skills can all be seen as conforming to a "fluid intelligence" trajectory, albeit with slight differences among them. They all develop quickly during childhood and adulthood, peaking between the ages of 20 and 30 years and they deteriorate at a regular, almost-linear pace across middle and late adulthood. In comparing cross-sectional and longitudinal data we have already mentioned how they are differently affected by practice and learning. Processing speed appears to be the least "learnable" of these abilities, consistently sticking to its developmental path regardless of environmental and experiential factors. Other skills, such as memory or inductive reasoning are more sensitive to experience. A suggested discriminant here is that some skills are based on the application of strategies – which can be learned and improved – while others rely on more basic processing. Vocabulary and general knowledge are the skills more often used to capture crystallised intelligence, and they tend to improve at a slower rate than fluid abilities in childhood and adolescent, but also to improve continuously through the entire early and middle adulthood. Here, too, it is possible to observe differences among individual abilities (or even individual tasks, as illustrated by Salthouse's (2014) study mentioned above), but they all share the fact that they only decline in older age – between the 60's and the late 80's.

Deviating from this framework, some research has suggested that age-related changes in cognitive abilities are more heterogeneous than the fluid/crystallised distinction suggests. Hartshorne and Germine (Hartshorne & Germine, 2016) showed that working memory appears to peak significantly later than "fluid" tasks such as processing speed, but significantly earlier than "crystallised" tasks such as vocabulary knowledge, constituting a third developmental pattern. These results are based on the study of individual task scores, and the authors suggest that these differences may be partly explained by the learning processes relevant to each task (e.g., learning that requires actually experiencing a stimulus, such as encountering a specific word, versus strategy-based learning, e.g., learning a strategy to keep a long series of digits in mind).

Additionally, an important element to determine when performance declines due to ageing is the measure to which some abilities can be compensated for by strategies.

1.1.3.1. The dynamic dedifferentiation hypothesis.

There is a peculiar phenomenon concerning cognitive trajectories in later life. Individual abilities develop at different pace throughout childhood and adulthood, but older age, starting approximately at 70 years, is characterized by decline in virtually all skills. The magnitude and direction of cognitive change seem to become progressively more similar across cognitive abilities with advancing age. This phenomenon is usually referred to as "dynamic dedifferentiation". A recent meta-analysis by Tucker-Drob and colleagues (Tucker-Drob et al., 2019), conducted over more than 30000 participants in 22 distinct studies, looked at this phenomenon in detail. The analysis reported that variability in longitudinal cognitive change is shared across cognitive abilities. In other words, if an individual declines more steeply than others in memory, they are also likely to decline more steeply in other skills, such as reasoning, spatial abilities, or processing speed. Moreover, the amount of shared variance increases with age across adulthood. At age 35, an average of 45% of variance in cognitive change rates is shared across cognitive domains. At age 85, around 70% of the variance is shared.

Study 1 offers an example of dynamic dedifferentiation observed within a narrow-age birth cohort. Participants in the study were all born in the same year, and they participated in extensive cognitive assessments in older age, starting from age 70 until age 82, at three-year intervals. Their visuospatial, memory, processing speed and crystallised abilities were assessed. A study conducted on data from the first three assessments (i.e., age 70 to 76) found that around 40% of the variability in age-70 cognitive performance and 48% of the variability in change rates between 70 and 76 years were shared across domains. Study 1, which uses data from 5 consecutive assessments (i.e., age 70 to 82) confirmed the proportion of shared variance in performance at age 70 (42.13%), but found that, over 12 years, the proportion of shared variance in change rates increased to an average of 63.11%. So, the LBC, as longitudinal narrow-age cohort studies, are a case in point of dynamic dedifferentiation, having shown an increase in shared slope variance over longer periods of time.

1.1.4. Individual Differences in Cognitive Ageing

While age-related cognitive decline is an established phaenomenon, consistently observed (Deary et al., 2009; Wilson et al., 2002), its manifestation is far from uniform and its mechanisms are not completely understood yet. Within the general trend of cognitive ageing there is, in fact, considerable interpersonal variability, as well as domain-specific trajectories (Zaninotto et al., 2018).

Cognitive change in old age is a gradual process and differences between individuals who meet diagnostic criteria and individuals who do not can be small. Even physiological decline can severely impact daily life and activities. Indeed, reduced cognitive functioning is in itself associated with lower quality of life and it can lead to loss of autonomy, illness and death (Batty et al., 2016; Deary et al., 2009). An increasingly longer life expectancy, not entirely matched by an increase of healthy life expectancy (Crimmins, 2004; Wanless, 2004), has made cognitive decline, together with other age-related conditions, one of the most urgent issues for modern science to investigate. As our societies grow older (Rousson & Paccaud, 2010; United Nations DESA, 2015), these phenomena will affect a growing number of individuals, with clear personal, societal and financial consequences. During later phases of life, beginning approximately at age 70, risk for cognitive decline substantially increases (Deary et al., 2009; Marmot et al., 2003) as does risk for dementia (Berr et al., 2005; Jorm & Jolley, 1998; Santoni et al., 2015) and mortality (Rousson & Paccaud, 2010).

Research on cognitive ageing has examined the structure, dynamics and correlates of cognitive abilities in old age (Salthouse, 2019; Tucker-Drob et al., 2014). Studies identifying predictors of cognitive ageing have examined both the correlates of individual differences in cognitive *levels* in older age (cross-sectional), and the correlates of individual differences in cognitive *changes* (longitudinal). Socio-demographic, cognitive, genetic, and physical correlates have been studied. Of these, education, physical activity, cardiovascular risk factors (i.e. diabetes, obesity, smoking, and hypertension), age and possession of the *APOE* e4 allele have shown the most robust associations with cognitive functioning (Baumgart et al., 2015). However, factors related to peak cognitive level in adulthood do not necessarily have a comparable association with cognitive decline rates (Corley et al., 2018; Ritchie et al., 2016; Tucker-Drob et al., 2019). Longitudinal data is therefore considered a more robust portrayal of the dynamic within-person changes that characterise cognitive ageing, as it can parse apart predictors of cognitive level from predictors of subsequent changes.

Understanding the nature, predictors, and mechanisms underlying such individual differences in ageing is vital for tackling the disruptive effects of cognitive decline, reducing the risk of associated pathologies, and designing ways to cope with the changes, promoting a successful model of ageing. In this context where changes occur across most of the adult life, the timing of interventions becomes an especially complex matter (Plassman et al., 2010); the accurate prediction of trajectories of cognitive decline is of the utmost importance to better understand potential mechanisms, but also to identify those at greatest risk (Brayne, 2007; Deary et al., 2009).

Numerous studies have addressed this issue comparing cognitive abilities at different ages in order to distinguish factors that influence peak levels in adulthood from factors that influence rates of change. Childhood cognitive ability, education, and genetic factors are among the strongest predictors of the *level* reached by cognitive abilities in adulthood (e.g., Corley et al., 2018; Stern, 2002; Zaninotto et al., 2018). In contrast, very few of the factors considered have shown significant individual associations with rates of cognitive decline. Of these, sex (being male), lower physical fitness and possession of the *APOE* e4 allele have emerged as the most robust predictors of steeper cognitive declines (Blondell et al., 2014; Ritchie et al., 2017; Tucker-Drob, 2019; Zaninotto et al., 2018). Other variables, such as age, childhood IQ, education, alcohol consumption, and diet (Loef & Walach, 2012; Morris, 2012), exhibit weaker and less stable effects, but they still contribute to explaining an appreciable amount of variance in cognitive ageing trajectories when included in models with multiple predictors (Corley et al., 2018). These results suggest that cognitive ageing depends on the small contributions of a large number of factors.

1.2. Cognitive Reserve

1.2.1. A Reserve to Explain Individual Differences in Cognitive Trajectories

In the context of neurology and cognitive psychology, Reserve is a heuristic, a concept elaborated to explain individual differences in the clinical, cognitive, or functional outcomes of brain damage, or of brain aging. The notion of Reserve stems from the observation that there is no strict correspondence between the extent of brain tissue damage and the manifestation of cognitive or functional impairment (Stern et al., 2018): Individuals who are more *resilient* to neural damage, better able to preserve their mental abilities, are believed to be endowed with a greater Reserve of protective resources.

The term was first used with this connotation in a work by Katzman et al. (1988). Upon conducting post-mortem brain examination on a sample of retirement home guests, Katzman and colleagues discovered that approximately 10% of participants who had been evaluated as functionally healthy displayed in fact a number of amyloid plaques similar to that of participants diagnosed with dementia. Moreover, while alive these participants had scored in the top 5% of the sample on cognitive tests. The distinguishing feature of individuals showing pathological brain damage without a corresponding clinical manifestation was that, on average, their brains were heavier or larger than those of their counterparts with dementia. Katzman's research team thus hypothesized that the "clinically healthy" group owed their better outcome to a greater initial *Reserve* of neurons, which had allowed them to withstand brain tissue degeneration while still retaining enough healthy tissue to ensure unimpaired cognitive functioning.

In the 30 years since Katzman's publication, the concept of reserve spread rapidly and several theories of reserve developed in parallel between the end of the 20th and the beginning of the 21st century. Naturally, there were considerable overlaps among these theories, besides their differences in terminology and perspective, but it was only recently that the field began to reach a more unified view. An essential step in this direction was the proposal of shared definitions of reserve and its mechanisms, elaborated by the workgroup constituted within the reserve, resilience, and protective factors professional interest area (Stern et al., 2018).

1.2.2. Mechanisms of Reserve

A common feature of the theories developed following Katzman and colleagues' proposal was that they structured Reserve around several mechanisms, pathways or components. Indeed, it quickly became apparent that interindividual differences in the cognitive outcome of ageing and pathologies could not be explained on the basis of brain structure alone. Just as people with similar pathology load had been found to exhibit different clinical outcomes, further studies revealed that people with similar pathology load *and similar brain structure* would also exhibit different clinical outcomes. Reserve theorists hypothesized that the residual variability was due to differences in brain function, thereby expanding the focus of their research to include the functional dimension of brain activity. For instance, Stern developed a theory of reserve mechanisms comprising Brain Reserve and Cognitive Reserve (Stern, 2002, 2009). In contrast, Valenzuela and colleagues discussed a Brain Reserve that had a behavioural component associated with education, occupation, and leisure activities (Valenzuela & Sachdev, 2006). Jones referred to the concept of Neurocognitive Reserve encompassing both structural and functional mechanisms (R. N. Jones et al., 2010). The above-mentioned whitepaper (Stern et al., 2018) proposed consensus definitions of Reserve-related constructs, identifying three mechanisms within Reserve: Brain Reserve, Brain Maintenance and Cognitive Reserve.

1.2.2.1. Brain Reserve.

Brain Reserve (BR) is the term used to refer to neurobiological capital (Stern et al., 2018) and it denotes the resources provided by structural brain features such as volume, or weight, or neuron/synapses count. Among the three proposed mechanisms of reserve, it bears the strongest resemblance to the concept initially proposed by Katzman and colleagues (Katzman, 1993; Katzman et al., 1988). The idea behind BR, in fact, is that larger brains can withstand greater amounts of damage before incurring in negative outcomes such as symptoms of dementia or other cognitive impairment (Stern et al., 2018).

Models of BR are also defined as threshold or passive models of reserve. Threshold models assume the existence of a cut-off for functional impairment, and postulate that brain damage becomes manifest (i.e., clinically or functionally) only after exceeding the cut-off. Conversely, sub-threshold brain damage remains unobserved (Satz, 1993). Greater BR thus confers protection because it represents a larger initial capital, and it requires more damage before being critically depleted. These models rest on two assumptions: (i) that the functional impairment cut-off is fixed and similar across individuals and (ii) that a given kind of brain damage will have the same effects across individuals.

There is ample evidence of the protective effects of BR, usually assessed through anatomic measures such as brain volume, head circumference, synaptic count, or dendritic branching (Stern, 2009). However, BR models alone cannot account for the full spectrum of individual differences in susceptibility to brain insult or pathology. For instance, they cannot account for variability in task processing in relation to neural damage, nor for qualitative differences between types of brain damage.

1.2.2.2. Brain Maintenance.

Brain Maintenance (BM) is defined as reduced development over time of age-related brain changes and pathology based on genetics or lifestyle (Stern et al., 2018). It refers to the preservation of brain structural, functional, and neurochemical integrity, which tends to diminish with advancing age, or because of illnesses. Indeed, the trend of age-related deterioration has been clearly evidenced by cross-sectional studies comparing younger and older participants. However, the same studies also found considerable variability in measures of brain health within each group (Nyberg et al., 2020; Raz et al., 2005; Rieckmann et al., 2011).

The hypothesis giving rise to BM was that there exist processes capable of influencing brain deterioration, avoiding it or slowing it (Nyberg et al., 2012), and that these processes are affected by individual factors, whether innate (e.g., genetic) or related to lifestyle and experience. BM encompasses all of these processes. The construct is closely related to BR, inasmuch as both mechanisms refer to brain structure. On the other hand, BM's features clearly distinguish it from BR. First, unlike BR, which characterizes brain status at a given time, BM is an intrinsically dynamic construct concerned with the processes governing change across time. Second, whereas BR protects against the effects of brain damage, BM protects against the accumulation of the damage itself (Stern et al., 2018).

1.2.2.3. Cognitive Reserve.

Cognitive reserve (CR) is the adaptability of cognitive processes that helps to explain differential susceptibility of cognitive abilities or day-to-day function to brain aging, pathology, or insult (Stern et al., 2018). In other words: The way a person's brain processes tasks can determine how well they are able to cope with brain damage while maintaining their cognitive function intact. A more adaptable task processing allows for better coping; therefore, it represents a protective resource against the negative effects of brain damage, a functional Reserve. As mentioned at the beginning of this section, the inclusion of a functional dimension has characterized all theories of reserve, despite the often-misleading differences in terminology (e.g., Valenzuela et al.'s *Behavioural Brain Reserve*, 2006). This was based largely on the substantial evidence that intelligence and autobiographical factors such as education, occupation, physical and leisure activities are associated with physiological cognitive ageing and with the incidence and severity of brain pathologies in old age (Opdebeeck et al., 2016; Pettigrew & Soldan, 2019; Scarmeas & Stern, 2003). CR is characterized as an active model of reserve, in contrast with BR's passive one, because it represents the brain's active attempts to cope with brain damage. Active models make no assumption regarding a fixed functional impairment cut-off, nor regarding the effects of brain damage. Rather, they focus on how functional brain processes are activated to buffer the cognitive expression of brain damage (Stern, 2002). The processes encompassed by CR can be present before the onset of brain pathologies and be responsible for greater efficiency in the execution of typical cognitive tasks. Or, they can be compensatory processes, enlisted expressly to keep executing typical cognitive processes even in the face of reduced neural tissue (Stern et al., 2018).

Despite the fact that the conceptualization of CR is centred on the functional level of analysis, it is important to clarify the possible links to its neural implementation. The neural correlates of CR can be found in networks of brain areas associated with the performance of cognitive tasks (Stern et al., 2018). The characteristics of neural networks give raise to the adaptability of cognitive processes. Three properties, in particular, have been proposed as the basis for CR: network efficiency, capacity and flexibility. Efficient networks require little activation to successfully perform their task, compared to the greater activation necessary to achieve the same results with less efficient networks. Network capacity, on the other hand, is the greatest level of activation achievable by a network, and it is important because it determines how well the network can carry out its task, maintaining consistent results, in the face of increasing demands: networks with greater capacity can scale their activation to handle greater demands. Finally, flexibility is not a feature pertaining to a single network, it is instead the availability of various networks that can all be used to perform a given task. A greater flexibility means that there is a greater number of cognitive processes that can potentially be enlisted to ensure optimal results under different circumstances, to meet specific demands or to work around a range of different limitations.

1.2.2.4. Complementary mechanisms.

The three mechanisms of reserve should be considered as complementary rather than at odds with each other (Barulli & Stern, 2013). Areas of overlap between the constructs can be perceived from the descriptions given above. For instance, BR and CR may be more closely related than originally theorized. Besides the metaphor of the hardware and software (Borenstein et al., 2006) that sees cognition ultimately relying on brain structure for its implementation, a growing body of evidence shows that brain anatomy (e.g., the number of neuron and synapses) is modifiable and sensitive to experience throughout adulthood (Lövdén et al., 2013). Thus, variables ostensibly related to CR, such as education, may also dynamically shape its underlying neural substrate (Stern, 2002). BM fits naturally in this picture. As already mentioned, brain maintenance processes may echo the influences of both genetics and lifestyle, and represent one of the pathways linking life experience and brain anatomy. Ultimately, BR,BM, and CR are likely to bring a synergic as well as independent contribution to cognitive resilience against the effects of brain ageing or pathology, thereby justifying their conceptualization as individual mechanisms within reserve, rather than as entirely independent constructs.

1.2.3. The Assessment of Cognitive Reserve

How can we measure "the adaptability of cognitive processes?" The premises of CR are such that, if its causal pathways can be shown to be reasonably strong and in a supportive direction, it could be promoted at the societal level as a preventive measure against cognitive decline (R. N. Jones et al., 2011). Therefore, developing a clear picture not only of CR as a construct but also of the appropriate methods to handle it in research settings is very important, and since the first conceptualization of CR it has also been one of the most debated issues. The challenges associated with the operationalization of CR require us to think critically about our concepts of intelligence, of cognitive change and of the role that lifestyle and environmental factors play in cognitive development. Since the concept of CR was first proposed, the field has been evolving alongside other related ones, such as neuropsychology, cognitive epidemiology, brain imaging, and latent variable modelling. This progress continues to shape the conceptual frameworks and the tools involved in the assessment of CR. However, as a theoretical construct related to functional brain mechanisms, the nature of CR poses a complex challenge to its evaluation. For this reason, rather than a single straightforward measurement, several different approaches have developed. The most common and validated assessment methods currently rely on indirect indicators: education, occupation, engagement in cognitively stimulating activities, and cognitive ability are all frequently employed as CR proxies.

1.2.3.1. Challenges and methodological approaches to CR evaluation.

The challenges in CR evaluation have different origins. The first issue concerned concept delineation, as the early theorists proposed similar but not identical definitions of CR to guide studies of construct validation. A second reason why CR is difficult to assess is that it refers to something not directly observable. Initially, it was regarded as a purely hypothetical construct (e.g., R. N. Jones et al., 2011; Meng & D'Arcy, 2012), and even though the 2018 consensus paper also clarified links between CR and its neural correlates (i.e., in terms of adaptability of neural networks), the relevant brain properties cannot be reliably observed yet.

The literature reveals three general approaches to the measurement of CR: the residual approach characterizes it as the interindividual variance in cognitive function that cannot be attributed to differences in brain status or demographic factors. The neuroimaging approach is based on the identification of functional activation brain networks that may underlie CR. Finally, the method based on sociobehavioural proxies looks at indirect indices assumed to covary with and contribute to the development of CR (Stern et al., 2018). The first two approaches both require brain measures: In the residual approach, brain structure and pathology need to be considered in order to control for their influence on cognitive function; in the neuroimaging approach, the evaluation of functional brain processes through neuroimaging techniques is the main focus of the assessment. The constant technological advancements are making brain measures increasingly valid, reliable, and accessible. However, other problems remain to be solved. The most significant issues with the residual approach are its close dependence on the other variables included in the residual model (Pettigrew & Soldan, 2019) and the fact that, in defining CR by exclusion, there is a considerable risk of confounding it with things other than reserve (Stern et al., 2018). On the other hand, the imaging approach is auspicious because it would represent the most direct evaluation of CR among those available, but it is still very recent (see e.g., Anthony & Lin, 2017). Hence, sociobehavioural proxies are currently the most popular indicators of CR (Opdebeeck et al., 2016; Pettigrew & Soldan, 2019).

1.2.3.2. Assessing CR through sociobehavioural proxies.

There are four typical CR proxies: IQ, education, occupation, and engagement in cognitively stimulating activities (Pettigrew & Soldan, 2019; Stern et al., 2018). Each of them "presumably reflects life experiences, above and beyond that of age, that have the potential to provide protection against clinical manifestation of disease in the brain" (Siedlecki et al., 2009). Arguably, IQ is distinct from the other three proxies: cognitive tests measure performance and are strongly influenced by innate levels of neural efficiency and processing, albeit also being subjected to the effects of experience (Hannigan et al., 2015; Nucci et al., 2012). IQ can be incorporated in CR measurement either as childhood cognitive ability intended to evaluate innate skills or as adult crystallised intelligence, the set of cognitive abilities developed through learning and experience, such as vocabulary or general knowledge. Education, occupation, and engagement in cognitively enhancing activities, on the other hand, reflect exposures to intellectually enriching life experiences. Each has shown associations to higher cognitive ability and reduced risk of mild cognitive impairment and dementia (Pettigrew & Soldan, 2019; Scarmeas & Stern, 2003; Valenzuela & Sachdev, 2006). However, it is difficult to draw detailed comparisons among the three indicators, and even to find in the literature consistent results regarding their role as protective factors, due to the inconsistency with which each of them is measured across studies. For instance, education is variably defined as years of formal education or educational achievement level, and occupation can be investigated in a specific time or over the whole lifespan (R. N. Jones et al., 2011; Satz et al., 2011). Instead, one finding that has emerged repeatedly from studies considering more than one proxy is that their cognitively protective effects appear to be additive, each indicator bringing an independent contribution to CR (Chan et al., 2018; Clare et al., 2017). Life-course studies even generated evidence that measures of education, occupation and engagement on cognitively stimulating activities synergically interacted with each other (Dekhtyar et al., 2015; Jefferson et al., 2011; Richards & Deary, 2005). Taken together, these findings are in favour of an assessment of CR based on multiple indirect indicators that can provide a comprehensive representation of individual life experiences, as well as of the lifelong pattern of interactions among lifestyle factors in youth, middle and older age (Kartschmit et al., 2019; Pettigrew & Soldan, 2019). Moreover, there is evidence that measuring CR on the basis of a single indicator can be problematic, preventing discernment of the true pathway through which it can affect cognitive ageing (R. N. Jones et al., 2011; Satz et al., 2011). Composite measures based on multiple indicators are usually preferred.

1.2.3.3. CR assessment tools.

Given the complexity of CR operationalization and its short history, it is not surprising that CR assessment tools are still in a relatively early stage of development. These instruments usually take the form of questionnaires investigating a combination of sociobehavioural proxies. Two recent systematic reviews (Kartschmit et al., 2019; Landenberger et al., 2019) have identified six published questionnaires: the Cognitive Reserve Index questionnaire (CRIq; Nucci et al., 2012), the Cognitive Reserve Questionnaire (CRQ; Rami et al., 2011), the Cognitive Reserve Scale (CRS; Leon et al., 2011), the Lifetime of Experiences Questionnaire (LEQ; Valenzuela & Sachdev, 2007), the Premorbid Cognitive Abilities Scale (PCAS; Apolinario et al., 2013), and the Retrospective Indigenous Childhood Enrichment (RICE; Minogue et al., 2018). All the questionnaires assess two or more experience-based proxies of CR. Five of these (CRIq, CRQ, CRS and LEQ and RICE) were developed for the general adult population and can be self-administered, whereas the PCAS is specific for low-educated populations with dementia and is designed to be filled in by a relative. Kartschmit et al. (2019) reviewed the methods used in the validation of the instruments and their psychometric properties. Overall, the studies conducted so far do not provide a sufficiently thorough assessment of measurement properties offered by the instruments. There was especially a lack of studies investigating content validity, structural validity, and responsiveness of the tools. At the current state of the art, however, it appears that the CRQ and CRS have undergone the most thorough methodological scrutiny, whereas the LEQ and the CRIq place at the top of the list in terms of construct validity.

To conclude, we can say that the assessment of CR is still controversial. At the moment, it is mostly carried out through proxy indicators. It appears that considering multiple indicators is the best practice, and there are several available tools for the job, although they would benefit from more extensive validation. Other approaches, i.e., residual and imaging, may become increasingly available as brain measures become more refined and accessible. A CR based on experiences, therefore modifiable, and protective of cognitive functioning, is tremendously promising for an ageing population, so it is very important that we manage to understand it in depth.

1.2.4. Cognitive Reserve in Youth: Cognitive Reserve Potential

Cognitive resilience, as in the ability of cognitive processes to withstand brain damage, is usually considered particularly relevant in older populations, where the risk of both physiological and pathological brain ageing increases substantially (Marmot et al., 2003; Salthouse, 2010). However, flexible and adaptable mental processing represents a valuable resource throughout the lifespan. Here, we will discuss how CR is studied in reference to youth, and we will introduce the main focus of Studies 2 and 3 of this dissertation: the assessment of early-life experiences potentially capable of enhancing CR. We will address the contexts in which children's CR is investigated, and the methods used to assess it, pointing out some of the still open issues. Finally, we will introduce our proposal in relation to the existing research gaps, namely, the development of an experience-base measure of CR for adolescents.

The predictive value of reserve has been chiefly acknowledged with reference to neurological conditions in adults (Bigler & Stern, 2015; Pettigrew & Soldan, 2019), even though it has been argued that the concept should be extended to accommodate variation in healthy individuals' performance (Stern, 2002). As anticipated above, the bearing of age, as well as of health status, warrants some reconsideration. The long-standing accumulation of cognitive resources which the term reserve recalls as something "saved up" in time – is necessarily set up early in life and may contribute to individual differences in cognitive efficiency and resilience from a young age. Indeed, there are numerous references to the concept of reserve to explain the cognitive outcomes of early brain dysfunction (Donders & Kim, 2019; Ekmekci, 2017; Kesler et al., 2010), but the analysis of CR in youth is still sporadic and unsystematic, from both the theoretical and the methodological point of view.

1.2.4.1. The assessment of CR in youth.

So far, CR in youth has been studied in three main contexts: in relation to traumatic brain injury (Donders & Kim, 2019; Fay et al., 2010; Karver et al., 2014) and in relation to two paediatric degenerative pathologies known to affect cognitive function, namely Paediatric-onset Multiple Sclerosis (Ekmekci, 2017; Hosseini et al., 2014; Pastò et al., 2016) and Paediatric Acute Lymphoblastic Leukaemia (Kesler et al., 2010).

According to the literature, the typical indicators of children's CR are cognitive ability and parental education. The former is assumed to reflect predominantly genetic endowment and the effects of early-life cognitive stimulation. Higher cognitive ability is taken to include also more efficient, or more adaptable, cognitive processing, hence higher CR. It is frequently evaluated through comprehensive batteries that include tests of verbal ability, reasoning, memory, and speed of information processing, such as the WASI battery (Hosseini et al., 2014). On the other hand, parental education (and its more frequent substitute, maternal education) are specific to studies on children and nor commonly employed in adult CR assessment. Parental education has a double informational valence: It reflects genetic endowment shared between parents and their offspring, and it is correlated to environmental enrichment, learning experiences and quality of childcare, all of which contribute to cognitive development (Kesler et al., 2010). It could be said that the single measure of parental education fulfils in the young population the roles that education, occupation and leisure activities measures fulfil in adults: that of capturing experiential correlates of CR. We believe that IQ and parental education, however meaningful, cannot be expected to capture a breadth of life exposures comparable to that considered in studies with adults, especially when assessing adolescents.

1.2.4.2. Rationale for the use of experience-based CR indicators in youth.

Comparing research on CR in adults and in youth prompted us to a methodological consideration. Studies on adults that employed both cognitive and experiential proxies of CR suggest that life exposures can buffer against negative cognitive outcomes in older age, over and above the effects of premorbid cognitive ability (Nucci et al., 2012; Stern, 2002). For instance, Dekhtyar and colleagues (Dekhtyar et al., 2015) found that higher occupational complexity predicted a significantly lower risk of AD even after taking into account the effect of cognitive performance in childhood. Additionally, it has been shown that measures of CR based on multiple experience-based indicators (typically educational achievement, occupation, and engagement in cognitively stimulating activities) are more accurate and offer a more reliable representation of CR compared to single-indicator measures (Grotz et al., 2017; R. N. Jones et al., 2011; Kartschmit et al., 2019). However, studies on children and adolescents tend to use a single CR proxy, either IQ or parental education. To the best of our knowledge, there is no research exploring whether individual differences in cognitive resilience (i.e., the adaptability of cognitive processes in the face of brain damage) in youth are affected by personal life experience.

Of course, the amount of life experiences accumulated at a young age is by force small. Still, it can potentially constitute a source of interindividual variability, especially in adolescence, when the progressive enhancement of autonomy makes life environments increasingly dependent on individual actions rather than familial determinants. Moreover, childhood experiences represent the foundations on which lifelong CR is built, so they take on a double value: with respect to cognitive resilience in youth, and with respect to the possibility to develop an optimal CR across the lifespan. In relation to this, in Study 3 we will introduce our proposal to use the term *CR Potential* (CRP) to denote the set of early experiences and educational activities capable of fostering CR. Current proxies of CR are not appropriate for use on youth: The experiences they assess, while covering different phases of life, are not able to differentiate enough between individuals prior to adulthood. Suffice to think that years of education and type of occupation, two of the main proxies of CR in adults, have close to no variability among adolescents who are yet to complete their formal education. For this reason, we aimed at developing an experience-based measure of CR specific for youth, considering exposures relevant in the life of adolescents. The research work illustrated in the present dissertation, and particularly Studies 2 and 3, are dedicated to this objective.

II. STUDY 1

Cognitive change before old age (11 to 70) predicts cognitive change during old age (70 to 82)

Chapter adapted from:
Conte, F., Okely, J., Hamilton, O., Corley, J., Page, D., Redmond. P., Taylor, A., Russ, T.C., Deary, I.J., Cox, S.R. Cognitive change before old age (11 to 70) predicts cognitive change during old age (70 to 82), (*submitted to peer review Feb 2021*). Preprint doi: 10.31234/osf.io/h8739

2.1. Introduction

This work addresses individual differences in cognitive ageing from a novel perspective. Rather than studying how differences in age-related cognitive decline are associated with other factors, we examine cognitive change consistency across the life course. We and others have shown that *level* of cognitive ability ascertained in childhood relates strongly to *level* of cognitive ability in older age (Deary, 2014). Here, instead, we ask whether individual differences in cognitive trajectories across the earlier part of the life course (11 to 70 years) predict subsequent cognitive change, from age 70 to 82. The latter period of life generally sees more rapid and clinically important cognitive changes. Individual differences in cognitive ageing probably reflect an accumulation of small influences from numerous factors (Corley et al., 2018), many of which are likely to be already present in early- and mid-life (e.g., genetic factors, early-life cognitive ability, physical fitness, smoking). Therefore, it is essential to characterise the relationship between earlier-period and later-period cognitive trajectories across the life course.

Cognitive decline is one of the most feared aspects of ageing. It will affect a growing number of people as the world population ages: In many countries, the proportion of older adults is increasing (Rousson & Paccaud, 2010; United Nations DESA, 2015), and the longer life expectancy is not always matched by an increment in healthy life expectancy (Abbafati et al., 2020; Prince et al., 2015). Even non-pathological cognitive decline can affect daily life and activities. Reduced cognitive functioning is associated with lower quality of life, leading to loss of autonomy, illness, and death (Batty et al., 2016; Deary et al., 2009). Thus, the clear personal, societal, and financial consequences of cognitive ageing, even among the non-clinical majority, motivate urgent scientific investigation. During later phases of life, beginning approximately at age 70, the risk of cognitive decline increases (Deary et al., 2009; Marmot et al., 2003; Salthouse, 2010), as does the risk of dementia (Berr et al., 2005; Jorm & Jolley, 1998; Santoni et al., 2015).

There is considerable inter-individual variability within the general trend of cognitive ageing (e.g., Zaninotto et al., 2018). Understanding the nature, predictors, and mechanisms underlying such individual differences is essential for tackling the disruptive effects of cognitive decline and designing ways to cope with the changes, promoting a successful ageing model. In this context, where some cognitive changes occur across adulthood, from the 20s (Salthouse, 2010; Tucker-Drob, 2019), the timing of interventions becomes an especially complicated matter (Plassman et al., 2010). The accurate prediction of trajectories of cognitive decline is critical; it will help understand potential mechanisms better and identify those at relatively high risk (Brayne, 2007; Deary et al., 2009).

Longitudinal studies have emphasized the need to distinguish cognitive *change* from cognitive *level*; they show that an individual's cognitive level at any given age is, at best, weakly associated with their cognitive trajectory (Karlamangla et al., 2009; Tucker-Drob et al., 2019). Accordingly, factors related to peak cognitive level in adulthood do not necessarily have a comparable association with cognitive decline rates (Corley et al., 2018; Ritchie et al., 2016; Tucker-Drob, 2019). Research on correlates of cognitive ageing has tested genetic, socio-demographic, health, and lifestyle factors. Among the stronger predictors of steeper cognitive decline are sex (being male), lower physical fitness, and possession of the *APOE* ε4 allele, whereas others (e.g. childhood IQ, education) exhibit weaker effects (Blondell et al., 2014; Plassman et al., 2010; Ritchie et al., 2017; Tucker-Drob, 2019; Zaninotto et al., 2018).

We are unaware of research examining whether differences in cognitive change from childhood to later adulthood are predictive of the subsequent gradient of cognitive decline in older age. This is an important omission in research. If we knew that individual differences in cognitive change between, say, age 11 and 70 were associated with cognitive changes from age 70 to 82, we would have more confidence that addressing factors operating before older age could ameliorate cognitive decline in older age.

Here, we test the hypothesis that cognitive change in general and domain-specific abilities after 70 (i.e., visuospatial, memory and processing speed) might be predicted by cognitive change up to age 70. We use longitudinal data spanning 71 years from the Lothian Birth Cohort 1936 (LBC1396).

2.2. Methods

2.2.1. Participants

The LBC1936 is a longitudinal study of cognitive, brain, and general ageing. Participants were all born in 1936 and most took a test of general mental ability, the Moray-House Test (MHT) No. 12, at age 11 years, as part of the Scottish Mental Survey (SMS) of 1947 (Scottish Council for Research in Education, 1949). Between 2004 and 2007, i.e., at about age 70, 1091 probable SMS participants living in the Lothian area were recruited to join in the first wave of follow up testing to form the LBC1936. As of 2020, the LBC1936 participants have taken part in five assessment waves at approximately three-year intervals from age 70 to age 82. A description of the types of data collected at each wave is given in Taylor et al. (2018).

At baseline (Wave 1), the LBC1936 sample consisted of 1091 individuals (543 females, mean age = 69.58 years, sd = 0.83). Table 2.1 presents sample demographics for all waves. Participants for whom age-11 MHT scores in childhood were not available (n = 63) or deviated more than 3.5 sd from the sample mean (n = 6) were excluded from analyses involving age 11 to 70 cognitive change. The study was approved by the Lothian Research Ethics Committee (LREC/2003/2/39; Wave 1), the Multi- Centre Research Ethics Committee for Scotland (MREC/01/0/56; Wave 1), and the Scotland A Research Ethics Committee (07/MRE00/58; waves 2-5).

Table I.1 Sample characteristics by wave – LBC1936

	Wave 1	Wave 2	Wave 3	Wave 4	Wave 5
N	1091	866	697	550	431
M/F	548/543	448/418	360/337	275/275	209/222
Mean age (SD)	69.58 (0.83)	72.54 (0.71)	76.30 (0.68)	79.38 (0.62)	82.06 (0.47)

Note. N = number of participants participating in each wave of assessment, M= males, F = females. Age is expressed in years.

2.2.2. Measures

The Moray House Test No. 12 (MHT) was completed by participants at age 11 years and age 70 years (Wave 1) in the present study. It was called a “verbal reasoning” test, but its items assess a range of abilities, including word classification, reasoning, analogies, arithmetic, spatial reasoning, and following directions. The test provides a single general cognitive ability score, with a maximum value of 76. The MHT score correlated at about .80 with the Stanford-Binet Scale in a validation test conducted during the SMS (Deary, 2014; Scottish Council for Research in Education, 1949).

Cognitive ability from age 70 to 82 was assessed using a battery of 10 tests related to three cognitive domains, administered at each Wave from 1 to 5. Three tasks evaluated visuospatial ability: Matrix Reasoning and Block Design from the Wechsler Adult Intelligence Scale III^{UK} (WAIS IIIUK; Wechsler, 1998a), and Spatial Span forward and backward (the sum score of the two was used in the analyses) from the Wechsler Memory Scale III^{UK} (WMS IIIUK; Wechsler, 1998b). Three tests from the WMS III^{UK} evaluated verbal memory: Verbal Paired Associates immediate and delayed, Logical Memory immediate and delayed (for these two tasks, total scores were the sum of scores in the two conditions), and Digit Span backwards. Finally, speed of information processing was ascertained by the Symbol Search and Digit-Symbol Substitution tasks from the WAIS III^{UK}, by a Visual Inspection Time task (Deary et al., 2007), and by a Four-choice Reaction Time task (Deary et al., 2001). In the analyses, reaction times were multiplied by -1, so that, for all tests, higher scores indicated better performance. For a detailed description of test characteristics and administration, see Deary, Gow, & Taylor et al. (Deary et al., 2007).

2.2.3. Statistical Analysis

We hypothesized that individual differences in cognitive change observed between age 11 and 70 years would be significantly associated with individual differences in cognitive change between 70 and 82. To test this hypothesis, we conducted the following steps, which are described in greater detail below: (i) estimate cognitive change from 11-70 using the MHT scores measured at both ages; (ii) build measurement models for cognitive abilities from age 70-82 using data from the larger set of 10 cognitive tests; (iii) test the degree to which 11-70 cognitive change predicts cognitive ageing between 70-82; and (iv) test whether 11-70 cognitive change is independently predictive of 70-82 change beyond just age 70 cognitive level (Figure 2.1).

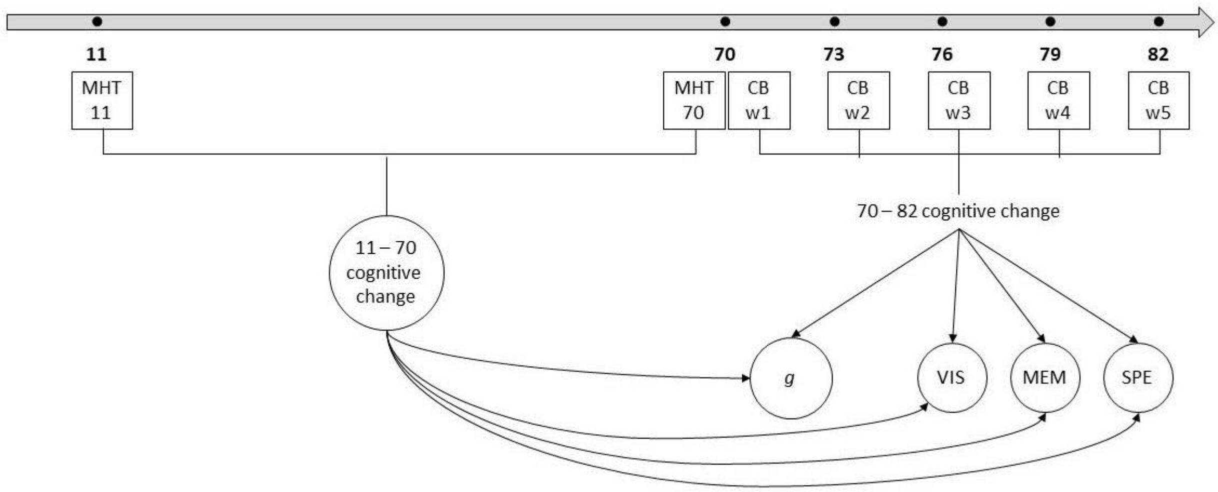

Figure II.1 Main analysis' diagram: age 11 to 70 cognitive change predicts age 70 to 82 cognitive

Note. 11- 70 Cognitive change estimated from Moray House Test (MHT) scores. 70 -82 Cognitive change in general cognitive ability (*g*) and in visuospatial (VIS), verbal memory (MEM), and processing speed (SPE) domains estimated from Cognitive Battery (CB) scores at Waves 1 through 5. 11-70 Cognitive change is usedto predict 70-82 cognitive change.

2.2.3.1. Deriving measures of cognitive change.

Cognitive change from 11 to 70 was modelled as the unstandardized residuals of the regression between MHT scores at Wave 1 (age 70) and age-adjusted MHT scores at age 11. This procedure has been used in previous LBC studies, such as Cherrie et al. (2018).

Cognitive change from age 70 to age 82 was estimated using a Factor-of-Curves model (FOCUS; McArdle, 1988). At the lowest level of the FOCUS model, ten linear latent growth curves (LGC) estimated change for each of the ten cognitive tests. Wave 1 (age 70) scores were considered the origins of the curves and scores from subsequent waves (ages 73, 76, 79, 82) were weighted based on the mean number of years that had passed since Wave 1. The LGCs provided, for each cognitive task, a baseline level parameter, representing mean scores at Wave 1 (age 70), and a slope parameter, representing mean change per year for the subsequent 12 years.

At the higher level of the FOCUS model, baseline level and slope for each of the three cognitive domains (speed, memory, and visuospatial) and for *g* were estimated as second-order factors from cognitive tasks' baseline levels and slopes. In this model, we fit a bifactor structure: each task parameter loaded onto its domain factor and the general factor simultaneously. The general factor was constrained to be orthogonal to the cognitive domain factors (Figure 2.2). Cognitive abilities are typically represented by hierarchical structures, with the most specific (i.e., individual task parameters) at the bottom and the most general (i.e., *g* parameters) at the top, separated by intermediate levels (i.e., domain parameters). This is also how LBC1936 data have been modelled in previous studies (Ritchie et al., 2016). In the present study, we instead fit a the bifactor model in which common variance (*g*) was partialled directly out of the cognitive test scores, and domains were modelled as factors using variance from which *g* had been removed. Despite making "residual" domain scores less intuitive to interpret, such a model offered an advantage over the hierarchical model: it allowed us to estimate the degree to which individual differences in cognitive ability changes from age 11 to 70 were associated with individual differences in *g* and orthogonal, domain-specific changes from age 70 to age 82. To repeat, any domain-related associations are independent of change that was common to all cognitive domains.

2.2.3.2. Estimating associations between age 11 to 70 and age 70 to 82 cognitive change.

We asked whether our measure of cognitive change between age 11 and 70 predicted subsequent cognitive declines in older age. To do so, we introduced 11-70 change in the model of cognitive change from age 70 to 82 (previously constructed – see above), as a predictor of the age-70 levels and the subsequent slopes of general and domain-specific cognitive abilities within older age. Factor loadings and intercepts obtained from the measurement model were fixed to aid model convergence, whereas the regression coefficients and residual factor variances were freely estimated. We introduced sex and the interaction term sex × cognitive change from 11 to 70 as covariates alongside our main predictor, to test whether the magnitude of any age 11-70 versus age 70-82 cognitive change correlation differed significantly as a function of sex.

Finally, we ascertained whether the measure of 11-70 cognitive change accounted for unique variance in 70-82 decline in *g* beyond baseline general ability at age 70. We recognize that 11-70

Figure II.2 Bifactor measurement model of cognitive level and change.
Note. Factor of curves models (not illustrated) are used to derive baseline level (bl) and slope (s) parameters for each cognitive task. General cognitive ability (g) baseline level and slope (left) and domain-specific baseline level and slope (right) are extracted as second-level latent factors from task parameters (center). BLD = block design, MTR = matrix reasoning, SSP = spatial span, VPA = verbal paired associates, LGM = logical memory, DSB = digit span backward, SBS = symbol search, DSS = digit-symbol substitution, ITT = inspection time, CRT = four-choice reaction time.

cognitive change would be correlated with baseline level of cognitive functioning; as discussed above,the latter has previously been shown to correlate weakly with cognitive ageing (Zaninotto et al., 2018).To examine the individual effects of the two measures (i.e., age 70 baseline level and age 11-70 cognitive change) we fitted a multiple regression model, with general cognitive decline 70-82 as a dependent variable, sex as a control variable, and with 11-70 change and the FOCUS *g* intercept (i.e., age 70 level) as simultaneous predictors of slope. Testing the magnitude of both predictors' effects, we ascertained whether cognitive change from age 11 to age 70 years would prove more informative thansimple age 70 scores in predicting trajectories of decline in *g*.

2.2.3.3. Supplementary analyses.

We calculated our main cognitive predictor (i.e., MHT change from age 11 to 70) as a regression-based score because these are arguably less affected by random measurement error compared to raw difference scores (Campbell & Kenny, 2002; Cronbach & Furby, 1970). However, we recognise that there is no clear consensus on the optimal measurement of change. Therefore, we conducted a supplementary analysis in which we used a raw difference score, also accounting for change reliability (see Appendix A - Supplementary Methods for additional detail).

Even though the current data benefitted from a narrow age range, there were small age differences for each assessment wave in older age. To ensure that these age differences did not substantially impact our results, we conducted a supplementary analysis. We fit a second version of the cognitive measurement model described, covarying the observed task scores with mean-centred age in days at the time of assessment.

Finally, in supplementary results, we present the association between 11-70 cognitive change and individual cognitive domains, without partialling out general cognitive variance (App. A - Supplementary Methods).

2.2.3.4. Peak-based measures of cognitive change.

The longitudinal data from the LBC1936 cohort provides insight on cognitive change over most of the human life course. The lack of assessments between ages 11 and 70 makes it difficult to identify specific phases of cognitive change, such as childhood development or the beginning of decline in adulthood. However, we can use some existing data to partially fill the 60-year gap. One of the other measures collected in the LBC1936 is the National Adult Reading Test (NART; Nelson & Willison, 1991). The verbal skills assessed by the NART improve throughout adulthood and are robust to some normal and pathological decline (Lezak et al., 2004). Various follow-up studies of the SMS, using the MHT, have validated the NART as an estimate of prior/premorbid cognitive ability (Crawford et al., 2001; Deary & Brett, 2015; McGurn et al., 2008). Deary, Whalley and Crawford (2004) showed that NART-included cognitive change estimates correlate strongly with measures of actual lifetime cognitive change. As a counterpoint to our primary analysis, we used age-70 NART score as an estimate of peak cognitive ability in adulthood. We then computed two additional regression-based indicators of cognitive change: age-11 MHT to estimated peak adult cognitive ability (i.e., age-70 NART); and estimated peak adult cognitive ability to age-70 MHT. The intention was to distinguish a phase of cognitive development from childhood to adulthood peak, from a phase of decline from peak to age 70. Consistent with the main analysis, age-11 MHT score was adjusted for age before regressing NART on it. Each of these indicators was tested as a predictor of cognitive change from 70 to 82, by introducing it in the cognitive measurement models in the same way we did with 11-70 cognitive change.

2.2.3.5. Software, fit and multiple comparison correction.

All models were estimated in the R environment (R Core Team, 2020) using package Lavaan (Rosseel, 2012) and a FIML (Full Information Maximum Likelihood) algorithm, which capitalises on information available from individuals even if they did not complete all assessments. We evaluated model fit based on the RMSEA, SRMR, CFI and TLI indices: RMSEA lower than .05, SRMR lower than .08, and CFI and TLI larger than .95 indicate good model fit (Hu & Bentler, 1999). The resultant *p*-values for the associations of interest were corrected for multiple comparisons with false discovery rate (FDR; Benjamini & Hochberg, 1995) using the "*p.adjust*" function from package Stats (R Core Team, 2020). Throughout the manuscript, we present standardised model estimates and the results marked as significant are those that survive FDR correction.

2.3. Results

2.3.1. Deriving Measures of Cognitive Change

Raw MHT scores showed a general improvement between age 11 (M = 49.26, SD = 11.34) and age 70 (M = 64.23, SD = 8.80), with a mean increase of 15.23 points (SD = 8.36), on a maximum possible score of 76 (+ 0.26 points per year, SD = 0.15). Figure 2.3 illustrates the distribution of the regression residuals of MHT age 70 on MHT age 11 interpreted as cognitive change measure in the analyses. Table 2.2 reports the correlation of the regression residuals with MHT at age 11 and 70, with *g* at age 70 (based on the cognitive battery), and with the raw change in MHT scores between age 11 and 70 (see sect. 2.3.3 and Supplemental material). The regression-based measure of MHT change had M = 0.00 and SD = 6.27.

Fit indices for the bifactor model of the levels and slopes of the ten cognitive tests are presented in Appendix A, Table A1, factor loadings in Table A2.

The cognitive measurement model fits the data well. An average of 43% of task variance in baseline levels was shared within *g*, 22.3% within domain, and 34.7% was task-specific. On average, 71.3% of slope variance was captured by *g*, 19.6% by domain factors, and 9.1% was task-specific. The strongest indicators of *g* slope, i.e., of change rates in general cognitive ability, were the processing speed tasks. Their loadings on the *g* slope factor ranged between 0.899 and 0.945, meaning that, on average, 85.5% of their slope variance was captured by *g*. This, in turn, resulted in little domain- specific slope variance beyond *g*: only 7.5%, on average, was shared exclusively among processing speed tasks (against 17.5% shared among visuospatial tasks, and 37.8% among verbal memory tasks).

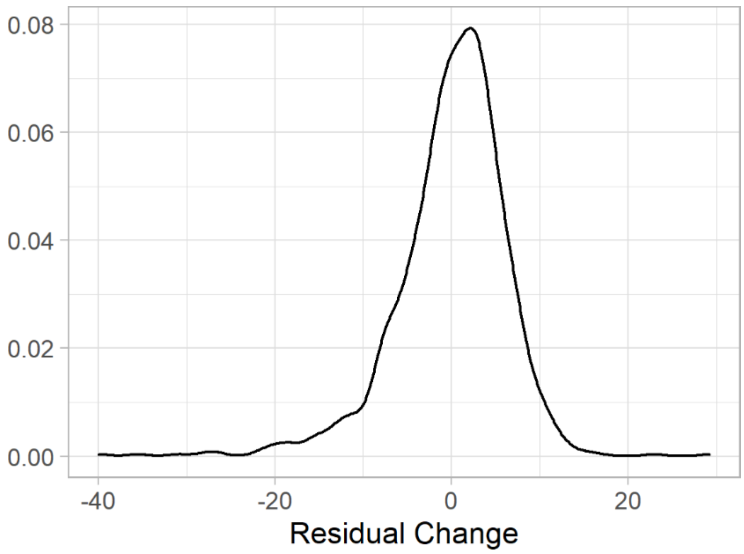

Figure II.3 Density plot of residual change scores of individual participants
Note: Residuals of the regression of Moray House Test scores at age 70 on Moray House Test scores at age ~ 11

Table II.1 Bivariate correlations between measures of general cognitive ability and 11-70 cognitive change

	11-70 residual change	MHT 11	MHT 70	g 70
11-70 residual change	-			
MHT 11	.00	-		
MHT 70	.74***	.68***	-	
g 70	.43***	.59***	.73***	-
11-70 raw change	.75***	-.67***	.10**	-.08*

Note: MHT 11 = Moray House Test scores at age ~ 11; MHT 70 = Moray House Test scores at age ~ 70 (Wave 1); *g* 70 = general cognitive ability at age ~ 70 (Wave 1); *g* was estimated through a Structural Equation Model including ten cognitive tests.
* p < .05 ** p< .01 *** p < .001

2.3.2. Cognitive Change From 11 To 70 as a Predictor of Individual Differences in Later-Life Cognitive Trajectories

Results of the present study's principal analyses are presented in Table 2.3. Table A1 reports model fit indices, which were good. A greater relative improvement in MHT score between age 11 and age 70 was associated with slower decline in g from age 70 to 82 ($\beta = .163$, $p =.001$): individuals who gain the most in MHT scores between age 11 and age 70 also tend to preserve their cognitive ability better from age 70 to 82. A more marked improvement in MHT score between age 11 and 70 was also associated with significantly higher g baseline level at age 70 ($\beta = .429$, $p < .001$).

MHT change between 11 and 70 remained a significant predictor of age 70-82 cognitive decline even after baseline age 70 level of *g* was entered as an independent variable in the multiple regression (11-70 change $\beta = .185$, $p < .001$; *g* baseline level $\beta = .080$, $p = .104$). Cognitive trajectories from age 11 to 70 thus appear more informative than does cognitive functioning at age 70 in predicting subsequent cognitive decline rates from age 70 to 82.

The next analyses involved changes in the cognitive domains from which variance in g had been removed. However, concerning their importance, note that there is about 3.5 times more slope variance in g than in the domains. The small amount of variance captured at the domain level warrants caution in interpreting these following results. More favourable 11-70 MHT cognitive trajectories were associated with less decline in verbal memory ($\beta = .139$, $p =.021$), but also with a steeper decline in processing speed ($\beta = -.198$, $p =.018$) (Table 2.3). There was no main effect of 11-70 MHT cognitive trajectory on visuospatial ability. However, we observed a significant cognitive change × sex interaction effect on the slope of visuospatial ability ($\beta = -.229$, $p =.010$), indicating that greater 11-70 relative improvement in MHT is associated with a steeper decline in visuospatial skills in women.

2.3.3. Supplementary Analyses

Supplementary Material presents results from our analyses (i) employing raw measures of 11- 70 MHT change, first on the entire sample and then on the subsample showing reliable change in scores, (ii) correcting for within-wave age differences, and (iii) fitting individual domain models but without partialling out general variance.

When conducting analyses on raw 11-70 MHT change, the direction and magnitude of effects on g level and change in the entire sample were consistent with those observed in the main analysis. No association with g slope was detected when assuming test-retest reliability of .90 for MHT scores at age 11 and 70. Raw 11-70 change had a significant positive association with the

Table II.2 Associations of cognitive change from 11 to 70 with later-life trajectories of general and domain-specific[1] cognitive abilities.

Effect	Baseline Level			Slope		
	β	C.I.	*p*	β	C.I.	*p*
g						
11-70 Change	**.429**	**[.37, .49]**	**.000**	**.163**	**[.07, .26]**	**.001**
Sex	**-.149**	**[-.21, -.08]**	**.000**	.088	[.01, .17]	.037
11-70 Change × Sex	.066	[.0. .13]	.056	.012	[-.08, .11]	.811
Visuospatial Ability						
11-70 Change	-.070	[-.16, .02]	.139	-.176	[-.36, .00]	.055
Sex	-.071	[-.16, .02]	.110	.090	[-.07, .25]	.279
11-70 Change × Sex	-.032	[-.12, .06]	.491	**-.229**	**[-.40, -.05]**	**.010**
Verbal Memory						
11-70 Change	.061	[-.02, .15]	.157	**.139**	**[.02, .26]**	**.021**
Sex	**.369**	**[.30, .44]**	**.000**	.044	[-.06, .15]	.415
11-70 Change × Sex	-.060	[-.14, .02]	.162	.016	[-.10, .14]	.790
Processing Speed[2]						
11-70 Change	.016	[-.07, .10]	.730	**-.198**	**[-.36, -.03]**	**.018**
Sex	**.368**	**[.29, .44]**	**.000**	-.114	[-.26, .03]	.123
11-70 Change × Sex	-.083	[-.17, .00]	.063	-.043	[-.21, .13]	.610

Note. Standardized coefficients and p-values. 11-70 change × sex = 11 to 70 cognitive change × sex interaction; proportion of domain-specific slope variance accounted for beyond g was: visuospatial 17.5%,verbal memory 37.8%, processing speed 7.5%. Bold typeface denotes FDR significant (q < .05).

[1] Bifactor model results: domain-specific variance does not include variance common to all tasks (capturedby g)

[2] The slope of 4-choice RT task loaded negatively on the domain factor.

slope of visuospatial ability, but not with the other two domains (see Table A3). Overall, the pattern of results reported above did not change when controlling for age differences within each wave of testing, as illustrated in Table A4.

The direction and size of effects in individual domain models (Table A5) are essentially similar to those observed on g in the main analysis, reflecting the large proportion of variance shared across domains.

2.3.4. NART-Based Measures of Cognitive Change and Individual Differences in Later- Life Cognitive Trajectories

We found that MHT change from age 11 to age 70 — i.e. across nearly six decades — predicted subsequent cognitive changes from age 70 to 82. We then used age-70 NART score as a measure of peak adult cognitive ability to investigate whether change from childhood to peak ability or change from peak ability to age 70 might be differentially important. Cognitive abilities were modelled using the same bifactor model as in the main analysis (see 2.3.1). MHT-11 to peak cognitive change had M = 0, SD = 5.82; it correlated with 11-70 cognitive change r = .37, p < .001. Peak to MHT-70 cognitive change had M = 0, SD = 6.59; it correlated with 11-70 change r = .73, p < .001.

Having higher NART scores than expected on the basis of age-11 MHT was associated with higher age-70 baseline level in *g* and domain-specific verbal memory (Table 2.4; β = .169 and .217, respectively, p < .001). However, this estimated 'early' cognitive change had no association with the change rates of any cognitive abilities investigated.

Having higher MHT-70 scores than expected on the basis of NART was associated with higher *g* level at age 70 (Table 2.5; β = .481, p < .001). It also predicted steeper decline after 70 in domain-specific visuospatial ability (β = -.234, p = .008). Overall, cognitive change over shorter timespans, either between age 11 and peak or between peak and age 70, appeared unable to predict decline rates in *g*. Supplementary Material reports model fit indices and individual domain models for these last analyses (Tables A1 and A5).

Table II.3 Associations of age 11 to peak cognitive change with later-life trajectories of general and domain-specific[1] cognitive abilities.

Effect	Baseline Level			Slope		
	β	C.I.	*p*	β	C.I.	*p*
g						
11- NART Change	**.169**	**[.10, .24]**	**.000**	.071	[-.02, .16]	.108
Sex	**-.212**	**[-.28, -.14]**	**.000**	.070	[-.01, .15]	.096
11- NART Change × Sex	.018	[-.06, .09]	.641	-.025	[-.11, .06]	.574
Visuospatial Ability						
11- NART Change	.070	[-.02, .16]	.127	-.093	[-.26, .08]	.285
Sex	-.067	[-.15, .02]	.132	.091	[-.08, .26]	.285
11- NART Change × Sex	.009	[-.08, .10]	.851	-.139	[-.31, .03]	.107
Verbal Memory						
11- NART Change	**.217**	**[.14, .30]**	**.000**	.071	[-.04, .18]	.191
Sex	**.349**	**[.28, .42]**	**.000**	.029	[-.07, .13]	.580
11- NART Change × Sex	.023	[-.06, .1]	.577	.018	[-.09, .13]	.737
Processing Speed[2]						
11- NART Change	.015	[-.07, .1]	.727	-.050	[-.20, .10]	.522
Sex	**.367**	**[.29, .44]**	**.000**	-.100	[-.25, .05]	.182
11- NART Change × Sex	-.021	[-.11, .07]	.628	.004	[-.15, .16]	.964

Note. Standardized coefficients and p-values. *NART* = National Adult Reading Test; *11- NART Change × sex* = 11 to peak cognitive change × sex interaction; proportion of domain-specific slope variance accounted for beyond *g*: visuospatial 17.5%, verbal memory 37.8%, processing speed 7.5%. Bold typeface denotes FDR significant.

[1] Bifactor model results: domain-specific variance does not include variance common to all tasks (captured by *g*)

[2] The slope of 4-choice RT task loaded negatively on the domain factor.

Table II.4 Associations of peak to age 70 cognitive change with later-life trajectories of general and domain-specific[1] cognitive abilities.

Effect	Baseline Level			Slope		
	β	C.I.	*p*	β	C.I.	*p*
g						
NART - 70 Change	**.481**	**[.43, .53]**	**.000**	.079	[-.01, .17]	.091
Sex	**-.141**	**[-.20, -.08]**	**.000**	.081	[.00, .16]	.059
NART - 70 Change × Sex	.077	[.01, .14]	.020	.001	[-.09, .09]	.990
Visuospatial Ability						
NART - 70 Change	-.061	[-.15, .03]	.182	**-.234**	**[-.41, -.06]**	**.008**
Sex	-.069	[-.16, .02]	.123	.077	[-.09, .24]	.364
NART - 70 Change × Sex	-.051	[-.14, .04]	.259	-.080	[-.26, .10]	.384
Verbal Memory						
NART - 70 Change	-.010	[-.09, .07]	.808	.102	[-.01, .22]	.086
Sex	**.363**	**[.29, .43]**	**.000**	.042	[-.06, .15]	.435
NART - 70 Change × Sex	-.050	[-.13, .03]	.241	-.017	[-.13, .10]	.777
Processing Speed[2]						
NART - 70 Change	.043	[-.04, .13]	.324	-.179	[-.34, -.02]	.028
Sex	**.372**	**[.30, .44]**	**.000**	-.118	[-.26, .03]	.113
NART - 70 Change × Sex	-.073	[-.16, .01]	.091	.029	[-.14, .19]	.728

Note. Standardized coefficients and p-values. *NART* = National Adult Reading Test; *NART - 70 change × sex* = peak to 70 cognitive change × sex interaction; proportion of domain-specific slope variance accounted for beyond *g*: visuospatial 17.5%, verbal memory 37.8%, processing speed 7.5%. Bold typeface denotes FDR significant.

[1] Bifactor model results: domain-specific variance does not include variance common to all tasks (captured by *g*)

[2] The slope of 4-choice RT task loaded negatively on the domain factor.

2.4. Discussion

2.4.1. Discussion

Our main finding is that individual differences in cognitive change between age 11 and 70 – measured on the same general ability test – significantly predict individual differences in g change from age 70 to 82 in this narrow-age cohort. We are not aware of other studies comparing cognitive change rates across these periods of life. The association we observed is modest but is at the upper bounds of effect sizes typically observed for individual risk and protective factors for cognitive ageing in this cohort (e.g., Corley et al., 2018) and others (e.g., Zaninotto et al., 2018). Moreover, age 11-70 change was informative about decline rates even when controlling for cognitive level at 70, thus offering independent predictive value. These findings accord with an account of differential preservation (Salthouse et al., 1990), whereby individuals with similar cognitive levels decline at different rates depending on the amount of cognitive change experienced from youth to older adulthood. Our results encourage the search for cognitive change determinants relatively early in the life course, not just because they matter in themselves, but because they are relevant to later-life cognitive decline.

The bifactor model differentiated variance shared among all cognitive tasks, and therefore attributed to *g*, from variance specific to each cognitive domain. Compared to a previous study on the same cohort, which considered the first three assessments (Ritchie et al., 2016), the present investigation on Waves 1 to 5 revealed a higher proportion of shared slope variance. This shift is consistent with Tucker-Drob's (2019) meta-analytic finding of dynamic dedifferentiation: g accounts for increasing amounts of variance with advancing age. Data from this and other studies (ibidem) shows that starting at age ~70 years, more than half of inter-individual variability stems from differences in the decline of general cognitive function, rather than of specific abilities. Therefore, accounting for change in g should be a primary focus of research on cognitive ageing. Bifactor models of cognitive ability can sometimes yield anomalous results (e.g., Eid et al., 2017). It is therefore encouraging to note that estimates from the current model are coherent with model estimated at earlier stages of the longitudinal LBC study (both hierarchical and bifactor), as well as with relevant literature such as the above-mentioned meta-analysis by Tucker-Drob.

The association of earlier cognitive change (11-70) with later cognitive decline (70-82) in g appeared robust in our study. Supplementary analyses showed that neither using an alternative measure of earlier cognitive change, nor introducing age as additional covariate changed this result appreciably. The predictive effect of 11–70 cognitive change seemed pervasive across domains of cognitive functioning, being significant also with regard to domain-specific decline. Greater relative improvement in MHT scores from age 11 to 70 was associated with better preservation of verbal memory and with steeper decline in processing speed and visuospatial abilities at later age (the latter only in women). These effects were less stable than those on g (e.g., they did not survive FDR correction in the age-adjusted model); however, we note again the small amount of domain-specific variance compared to general variance. Altogether, our results support the initial hypothesis that changes between childhood and late adulthood might be relevant to a broad range of cognitive changes after age 70, especially concerning general cognitive ability. These are the first data suggesting that those with more positive earlier trajectories are at lower risk of subsequent decline into older age.

Why did 11-70 change predict change in g better than in cognitive domains? First, in older age, there was much more variance in g change than in domain-specific changes. Second, the nature of the MHT test might have been relevant. The MHT correlates strongly with the Stanford-Binet overall IQ score in childhood (Deary, 2014) and with g in adulthood (Deary et al., 2010). Therefore, it was likely to be good at predicting subsequent change in g. Performance in specific cognitive domains at age 11 and 70 could have predicted domain-specific change better. We think it would be valuable if that could be tested for memory, which was the domain least related to g and is a signature of some types of mild cognitive impairment and dementia.

New questions arise as to what lifetime period might be most informative about age-related cognitive decline: would it be, say, between childhood and early adulthood, or from mid- to later-life? We partially answered such questions using the age-70 NART as an indicator of participants' peak cognitive ability and assessing change in rank orders from age-11 MHT to NART and from NART to age-70 MHT. Previous LBC studies showed that NART-based cognitive change estimates correlate strongly with actual cognitive change (Deary, Whalley, et al., 2004). Despite this, the absence of significant associations with rates of change in g suggests that neither MHT11-peak change nor peak-MHT70 change are in themselves sufficient to anticipate cognitive trajectories in older age. In this study, the longer timespan (i.e., from age 11 to 70) proved more informative about change rates in older age. However, additional research and alternative measures of cognitive change over shorter intervals (i.e., childhood to early adulthood, early to late adulthood) are needed to determine the relationship of cognitive change trajectories.

2.4.2. Limitations

Limitations should be considered when interpreting our results and may help inform future research. The LBC studies provide direct measures of participants' cognitive abilities in childhood and older age. However, no cognitive tests were administered in the years between ages 11 and 70 (i.e., 1947 and 2007). Therefore, information on this period is not as thorough as information collected from participants in their older age. However, we judge that a robust index such as the NART represents a valuable resource in the absence of direct assessments. We hope that our efforts to bridge this gap will motivate further research into potential critical periods during which earlier-life cognitive change anticipates later-life cognitive decline.

LBC1936 cohort members tend to be healthier, better educated, and perform better on cognitive ability tests compared to the population average (Taylor et al., 2018), likely leading to some restriction of range and a slight reduction in effect sizes (Johnson et al., 2011). Finally, participants were all born in a single year and come from a particular geographical setting, thereby limiting our results' generalizability, albeit removing the possibility of cohort effects in a mixed-age sample.

2.5. Conclusion

Research indicates that individual differences in cognitive decline arise from many diverse factors, each exercising a small influence (Corley et al., 2018; Deary et al., 2012). Tracing cognitive change trajectories back through the life course requires data that are rarely available. The present study shows that cognitive change between ages 11 and 70 is independently informative of cognitive change trajectories from age 70 to 82, beyond cognitive level at age 70. Therefore, the results support identifying individuals at higher risk of cognitive decline before the critical years in which dementia risk accelerates. The positive side to the findings is that, to some extent, those who fare better cognitively from age 11 to 70 tend to be at lower risk of cognitive decline from 70 to 82. As Fred Astaire (1899-1987) reportedly said, “Old age is like everything else… to make a success of it, you’ve got to start young.”

2.6. Aknowledgements

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III. STUDY 2

Intellect is not that expensive: Differential association of cultural and socioeconomic factors with crystallized intelligence in a sample of Italian adolescents

Chapter adapted from:
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3.1. Introduction

3.1.1. Verbal Abilities as a Measure of Crystallized Intelligence

In everyday life, the ability to efficiently understand and communicate with others is commonly considered as one of the basic signs of intelligence. Accordingly, both experts and laypeople seem to consider verbal abilities as a main aspect of human intelligence (Sternberg, 2015; Sternberg et al., 1981). Verbal skills have been indeed identified as indicators of cognitive functioning since the earliest modern theories of intelligence, with language-related factors appearing in Thurstone's *primary mental abilities* theory (1935), Cattell's *gf-gc* theory (1943), and Carroll's *three-stratum* theory (Carroll, 1993; Schipolowski et al., 2014). Tests of vocabulary knowledge (either lexical or semantic) are nowadays typically included in assessment batteries, such as the Wechsler scales (WPPSI-V, WAIS-IV, WISC-V; Wechsler, 2003, 2008, 2014), the Kaufman Assessment Battery for Children (KABC; Kaufman, 2004; Kaufman & Kaufman, 1983) and the Woodcock Johnson IV (Woodcock, R. W., Schrank, F. A., Mather, N., & McGrew, 2014) (for tests and batteries assessing language competences, see Flanagan et al., 2013). Verbal skills also play a predominant role in the differentiation between *crystallized intelligence*, which refers to acquired knowledge (e.g., of vocabulary or historical facts), and *fluid intelligence*, which refers to problem-solving abilities in tasks where previous knowledge is uninformative (Cattell, 1943). Building up on the earlier models outlined above, recent theories of intelligence consider vocabulary a fundamental form of culturally acquired knowledge, essential for individual success (Schneider & McGrew, 2012, 2018; Sternberg, 2015). For example, the Cattel-Horn-Carroll (CHC) model includes a factor called *comprehension-knowledge*, which is close to the historical conception of crystallized intelligence (Schneider & McGrew, 2018). Vocabulary tasks are commonly used instruments in this context, since they can assess two important aspects of comprehension-knowledge: verbal ability and general declarative knowledge (Flanagan et al., 2013).

Unlike fluid intelligence, once acquired, verbal skills are relatively stable and robust to aging and decline (but see Rinaldi & Karmiloff-smith, 2017). This has made the assessment of verbal skills, and consequently of crystallized intelligence, rather precise even in cognitively impaired individuals (e.g., Oliveira et al., 2014; Wittorf et al., 2014; Yuspeh & Vanderploeg, 2000). Vocabulary knowledge has proven relevant also for research focusing on the effects of learning or of life experiences on cognitive development. A recent example comes from the domain of *cognitive reserve*. Cognitive reserve is a construct developed to "explain individual differences in cognition, function, or clinical status following aging or brain disease" (Stern et al., 2018). By definition, cognitive reserve is susceptible to the influence of lifetime exposures such as education and occupation (Stern et al., 2018). In light of their stability in healthy aging as well as in neurologically impaired conditions, vocabulary test scores have been employed in the investigation of cognitive reserve as measures of baseline, pre-morbid cognitive functioning of patients with dementia, traumatic brain injuries or other brain conditions (Nucci et al., 2012). Although the general agreement is that cognitive reserve captures much more than vocabulary knowledge (Nucci et al., 2012; Richards & Sacker, 2003; Scarmeas & Stern, 2003; Stern et al., 2018), vocabulary test scores have occasionally been used as a proxy to summarize lifetime exposures and, as such, cognitive reserve itself (Karver et al., 2014).

3.1.2. The Mutualism Model of Intelligence

Models of intelligence explain the relationships among cognitive abilities, including the so-called positive manifold (i.e., the phenomenon of positive correlations among tests), in different terms. In the mutualism model of intelligence (H. L. J. van der Maas et al., 2006), positive correlations between cognitive measures are ascribed to mutual causal interactions among them and with the environment (H. Van Der Maas et al., 2017). An example of such interactions is described also in the investment theory (Cattell, 1987; H. Van Der Maas et al., 2017): The investment of fluid intelligence contributes to building up skills and knowledge that, once consolidated, might remain available in the form of crystallized abilities. Furthermore, consistent with the mutualism hypothesis, it has also been shown that crystallized abilities such as vocabulary skills can affect fluid intelligence throughout development (Kievit et al., 2017). The environment and its reciprocal interactions with abilities can also play a pivotal role in cognitive development, resulting in multiplicative effects over time (Dickens & Flynn, 2001; Nisbett et al., 2012). For instance, the physical and social environments we live in play a massive role in shaping our vocabulary by providing learning experiences, but the relationship between vocabulary and experiences seems to go both ways, as good verbal skills have been shown to facilitate new learning opportunities (Schwab & Lew-Williams, 2016).

These theoretical developments have gone hand in hand with the rapidly developing field of network psychometrics (Costantini et al., 2015; Epskamp et al., 2017; Epskamp, Borsboom, et al., 2018). In network models, cognitive abilities and environmental variables are represented as nodes and their mutual pairwise interactions are represented by undirected edges, with the weight of an edge corresponding to the importance of the relationship. Network models for continuous data are typically estimated through the Gaussian Graphical Model (GGM), in which edges represent the relationships between each pair of variables after controlling for other variables in the network, thus ruling out the possibility of spurious relationships, and in which statistical regularization promotes parsimonious models and prevents overfitting (Costantini et al., 2015; Epskamp, Borsboom, et al., 2018). Such undirected network models allow to examine the relationships among several cognitive abilities and relevant environmental conditions simultaneously (e.g., Kan et al., 2019), without needing to specify the direction of the effects, which is undetermined in cross-sectional studies (Epskamp et al., 2017; MacCallum et al., 1993). In this work, we use network models to examine the mutual relationships between verbal abilities, fluid intelligence, and the most important environmental factors that play a role in the development of verbal abilities in a large group of Italian adolescents.

3.1.3. The Role of Environmental Factors in the Development of Verbal Abilities

The association between verbal competence and environmental factors has been investigated in depth, particularly for what concerns the early stages of development. One of the main factors examined is socioeconomic status (SES), which represents an individual's relative position in society taking into account multiple dimensions, such as financial resources, occupational prestige, education, and social influence (Ensminger & Fothergill, 2003). For children, SES is usually estimated relying on parental level of education, occupational status, social class or family income (Letourneau et al., 2013). SES is a robust predictor of individual differences in language development (Hackman & Farah, 2009; Thomas et al., 2013) and research has linked economic, social and cultural assets of the family to students' educational outcomes, including verbal abilities (Bukodi & Goldthorpe, 2013; Dahl et al., 2012; Davis-Kean, 2005; OECD, 2016; Sirin, 2005).

SES is not the only component of the environment that has been investigated by previous research in relation to cognition. The Home Observation for Measurement of the Environment (HOME Caldwell & Bradley, 1984), for instance, combines interviews and direct observations to evaluate factors such as learning stimulation, physical environment, warmth and affection, activities outside of the home and responsibilities in the home. The HOME has been employed in various demographic and socioeconomic studies, such as the American National Longitudinal Study of Youth (NLSY; Dubow & Ippolito, 1994), as a measure of environmental conditions affecting cognitive development in young children (Bracken et al., 1993). Total scores on the HOME have been shown to correlate with children's verbal abilities (e.g., Luster & Dubow, 1992) and also to mediate the relationship between income and intelligence (Linver et al., 2002). Perhaps more interestingly, studies aimed at differentiating the roles of specific factors identified cognitively stimulating items and activities (e.g., parents reading to the child, presence of children books and magazines, museum visits) as having the strongest association to children's cognitive skills (e.g., Freeman, 1983; Guo & Harris, 2000).

In research stemming from a sociological background, this kind of environmental features all belong to a construct generally referred to as the family's *cultural capital*, the set of a family's resources pertaining to culture (Bourdieu, 1973; Bourdieu & Passeron, 1990). It is possible to identify three dimensions of cultural capital: an *institutionalized* cultural capital, the titles and professional qualifications through which a society formally acknowledges cultural mastery; an *objectified* cultural capital, all material belongings that hold cultural meaning and value; and an *incorporated* cultural capital, the attitudes and skills learnt through socialization (Bourdieu, 1986). Cultural capital is also strictly associated with economic and social capital (Barone, 2006): Resources pertaining to culture can be instrumental in achieving higher levels of education and consequently more advantageous positions in society (Bourdieu, 1973; Di Maggio, 1982). Unfortunately, the lack of shared assessment guidelines resulted in many ad-hoc measures of cultural capital in earlier research (Sieben & Lechner, 2019; Teachman, 1987). Yet, recent studies have shown that, among these different measures, those related to books, literature and reading have the most significant association to both cognitive abilities and life outcomes (Sikora et al., 2019). In particular, the single-item *books at home* index has become increasingly common in scientific research (Barone, 2006; Sikora et al., 2019) and it is currently included also in large-scale international comparison studies (Mullis et al., 2016; e.g., OECD, 2016). Interestingly, recent studies have shown that the number of books at home during childhood and adolescence predicts cognitive abilities and that cognitive abilities, in turn, mediate the effect of books at home on educational and occupational success (Evans et al., 2010; Sikora et al., 2019). Growing up in a book-rich environment, therefore, seems to represent a resource over and above SES: Having more books appears to be independently related to greater literacy and numeracy skills (Park, 2008). So far, the role of cultural capital has received much attention from a sociological point of view, whereas in psychological research different environmental features are more frequently reduced to a single indicator, such as the SES or the HOME (Guo & Harris, 2000). However, current dynamic models of intelligence have started to advocate more detailed analyses of the interactions between genes, cognition and environment (Rinaldi & Karmiloff-smith, 2017; H. Van Der Maas et al., 2017). For this reason, differentiating between the effects of cultural, economic and social resources is becoming increasingly common also in psychological research, especially in the field of developmental psychology. Nevertheless, this is far from being a standard practice and studies employing SES as a global indicator are still the majority (e.g., Tucker-Drob & Bates, 2016).

3.1.4. Assessment of Verbal Abilities

Due to the relevance of vocabulary knowledge in and beyond cognitive assessment, the notion of *word knowledge* itself has sparked interest in psychological research, resulting in the proposal of numerous assessment instruments. Yet, the definition of word knowledge is not as univocal as it may appear. An important distinction is the one between *productive knowledge* and *receptive knowledge*. Productive knowledge is the ability to spontaneously recall and use the appropriate word (Milton & Fitzpatrick, 2014), whereas receptive knowledge consists of recognizing a word’s characteristics, such as its meaning or pronunciation, when exposed to the word. For instance, the vocabulary subtests of the WAIS (Wechsler, 2008) and of the WISC (Weiss et al., 2016) assess productive knowledge by asking participants to provide the definitions of given words. On the other hand, the National Adult Reading Test (NART; Nelson & Willinson, 1982) and the Italian Test d’Intelligenza Breve (TIB; Colombo et al., 2002) assess receptive knowledge through complex reading tasks. Despite being frequently used in clinical settings, these tests are not designed for group administration. Tests of receptive knowledge based on the *lexical decision task* paradigm (Meyer & Schvaneveldt, 1971) are generally more agile: They can be self-administered, and have also been developed in many languages (Alderson & Huhta, 2005; Merz et al., 1975). However, knowing whether a word exists or not (the kind of knowledge at play in lexical decision) is not the same as understanding its meaning or grasping its appropriate use in linguistic contexts (e.g., Nation, 2000). This latter idea of word knowledge is the one that best grasps the concept of crystallized intelligence (Schneider & McGrew, 2018). Only a few tests have been developed for assessing receptive knowledge of word meaning and even fewer are available for the Italian language. For example, the Vocabulary Size Test (VST) is currently validated in English and in a number of Eastern/Asian languages including Arabic, Korean, Japanese and Mandarin (Nation & Beglar, 2007), but not in Italian.

3.1.5. Aims of This Study

The aim of this study is to map the relationships among verbal abilities, fluid intelligence and relevant environmental factors in a large group of adolescents. The reason for considering this age group is twofold**:** First, in adolescence, the progressive enhancement of autonomy makes life environments increasingly dependent on individual actions rather than familial determinants; second, intelligence and environmental conditions at this stage of life are strong long-term predictors of life outcomes in adulthood (Deary, Whiteman, et al., 2004).

With regards to verbal abilities, we focus on depth rather than breadth of vocabulary (i.e. knowledge of word meaning and use) as preferential index of crystallized intelligence. This aspect is reflected also in the structure of most assessment batteries (Flanagan et al., 2013). An examination of the literature indicates that there are no recently validated measures of semantic knowledge suitable for assessing groups of Italian speakers. In fact, the Verbal task included in the Primary Mental Abilities battery (Thurstone et al., 1957; Thurstone & Thurstone, 1949) is the only such measure available and the Italian version dates to 1957 (Thurstone et al., 1957). The PMA battery includes tests assessing several types of cognitive abilities and was originally developed by Thurstone (Thurstone, 1938; Thurstone & Thurstone, 1949) . The Italian version (Thurstone et al., 1957) was adapted from the 1949 American edition and targets three age-ranges (5-6, 7-11, 11-17). The first aim of our study was thus to adapt the original version of the PMA Verbal task to our setting, in order to reflect time-related changes in the Italian language and to make it suitable for digital administration, with the ultimate goal of examining its psychometric properties. The original version of the task obviously does not account for the evolution in the Italian lexicon and for changes in word frequency that occurred over time. For example, some of the words included in the test were relatively common when the test was originally developed but are now rather obsolete. Furthermore, the original task was conceived for paper-and-pencil administration.

In light of the role played by cultural capital in the development of cognitive skills, which has yet to be systematically investigated, the second aim of the current study was to explore in more details the relationship between cognition and relevant dimensions of adolescents' environment. Despite its explicatory power, SES alone cannot fully account for an individual's environmental resources, as it is based only on measures of social origins and economic status (Ensminger & Fothergill, 2003). Existing literature suggests that objects and activities of cultural relevance have a significant and unique influence on cognitive development (Freeman, 1983; Guo & Harris, 2000). Moreover, we believe it is worth considering an additional distinction between cultural factors, particularly material resources and personal activities. Material resources (e.g., home library), which can be likened to the objectified dimension of cultural capital (Park, 2008), are strongly *context-dependent* during childhood and adolescence, when the physical home environment is still predominantly shaped by parental figures. On the other hand, activities such as reading, which could be seen as one facet of incorporated cultural capital, can be influenced by *person-dependent* characteristics earlier in life, as individuals actively integrate the attitudes and habits common in their environment with their own inclinations and preferences. It is reasonable to expect that these personal choices would already be playing a role in adolescence, a time strongly deputed to gaining independence. This distinction resembles Bourdieu's idea that incorporated capital is not simply transferrable as a tangible inheritance (Bourdieu, 1986), as it is driven by individual engagement, practice and willingness in shaping cultural resources within a specific cultural context.

3.2. Methods

3.2.1. Participants

The study involved middle and high school students from four schools in Northern and Central Italy. Upon agreement with the schools, students and their families were contacted to ask for consent. A total of 550 students accepted to participate in the study. Due to the verbal nature of the test, participants who were not Italian native speakers were excluded from the analyses (N=56). Analyses were thus performed on a sample of 494 participants (245 females, mean age = 15.6 years, SD = 2.29).

The study was conducted in compliance with the regulations issued by the Ethics Committee of the University of [omitted for blind peer-review] (protocol number 448) and with the Helsinki Declaration (World Medical Association, 2013).

3.2.2. Procedure

Data collection was carried out at school adopting a CAWI (Computer Assisted Web Interviewing) methodology. All measures were in digital format and were administered collectively to the members of a class in the following fixed order: the PMA Verbal task, the cultural and socioeconomic context questionnaire and Raven’s Standard Progressive Matrices (Raven, 1941). The experimenters presented the study and provided instructions, supervision and support when required. Each student completed the tasks individually on a PC or tablet.

3.2.3. Measures

3.2.3.1. Cognitive measures.

PMA Verbal (α = .91). The PMA Verbal is a task of synonym recognition. The task consists of 50 target words, each presented together with five answer options, only one of which is a proper synonym of the target word. Participants are asked to indicate the correct synonym for as many words as possible within an established amount of time. The instructions emphasize both accuracy and speed. The words are presented in a fixed order and respondents can move back and forth between questions, skip or change their answers. We adapted the original version of the PMA Verbal task (Thurstone et al., 1957) to reflect changes in the Italian language that occurred over time. In particular, we evaluated the target words on a combination of two criteria: their frequency in the COLFIS corpus of Italian language (Bertinetto Pier et al., 2005) and their degree of familiarity measured in a preliminary study (i.e., 103 undergraduate students, attending the first year of the bachelor’s degree in Psychology, judged their familiarity with each word on scale from

1 = *not at all familiar* to 5 = *very familiar*). Five target words, which were both rare and unfamiliar (familiarity rating below the 10° percentile), were consistently judged to be no longer representative and, therefore, were removed. The adapted list consists of 43 low-frequency words (e.g., "Fecondo" - *Fecund*; frequency range 0.01 – 20.63), one medium frequency word ("Discussione" – *Discussion*; frequency = 58.73) and one high frequency word ("Guardare" – *to look*; frequency = 306.97). Furthermore, we increased the time limit from 4 to 7 minutes due to digitalized administration. In fact, whereas the paper-and-pencil version of the PMA Verbal task allowed easier scanning of the words with all stimuli printed on a single page, the digitalized version required scrolling and slowed task execution, as confirmed by a pilot study. Table B1 (Appendix B) lists frequency, familiarity, and answer options for all items, including also the stimuli excluded from the final version of the task.

Raven SPM (Bilker et al., 2012, α = .91). The Raven SPM was used as a non-verbal measure of fluid intelligence. All participants completed the standard version of the task, composed of five series of 12 matrices each, for a total of 60 items. In the Raven SPM, difficulty increases both within series and from one series to the next.

3.2.3.2. Socioeconomic and cultural measures.

Family background, home possessions (including books), participants' cultural habits and demographic characteristics were assessed through a 26-item questionnaire.

SES (α = .86). The overall SES index was based on the standardized values of educational attainment and type of occupation of both parents at the time of the interview. Following the International Standard Classification of Education (ISCED; UNESCO Institute for Statistics, 2012), we distinguished five levels of educational attainment (1 = *less than primary*, 2 = *primary*, 3 = *lower secondary*, 4 = *upper secondary*, and 5 = *tertiary*). Descriptions of occupational status offered by participants were used to determine parents' International Socio-Economic Index of Occupational Status (ISEI; Ganzeboom et al., 1992). The resulting ISEI index ranged from 10 to 90, with higher values indicating higher SES. These measures of family background were preferred over measures of financial resources for two main reasons. First, to reduce the risks of unreliable answers: Adolescents are more likely to report correct information on parents' education and occupational status rather than on family income. Second, these measures provide a richer representation of the family's socioeconomic status because they refer indirectly also to social resources such as contacts and networks of relations (Bukodi & Goldthorpe, 2013). A principal component analysis on educational achievement and ISEI of both parents clearly suggested a single-component structure. The eigenvalues were 2.84, 0.50, 0.42, and 0.24 and the first factor explained 71% of the total variance, with loadings ranging between .81 and .86. We therefore computed an overall SES index for each participant as the individual score on the first component.

Books at Home. The books at home index (OECD, 2013; Sieben & Lechner, 2019) consisted of a single-item in which participants reported the number of books in their household on a pictorial six-point response scale (*0-10 books; 11-25*; *26-100*; *101-200; 200-500; more than 500*).

Home possessions (α = .61). We assessed home possessions using a scale from the PISA 2015 study (OECD, 2016). Participants reported about the presence in the household of 10 different objects of cultural or educational significance (e.g., *"Are there educational apps/ software in your household?" "Are there artworks in your house, such as paintings?"*). An overall score was obtained as the simple count of items.

Reading habits (α = .84). Participants responded to three questions investigating their reading habits ("*In your spare time, how often do you read books, magazines or comics, excluding schoolwork?", "How often do you buy books, magazines or comics, excluding school material?", "How many books did you read last year, excluding schoolwork?")* on a 6-point scale ranging from 1 = *never* to 6 = *always* (for the first two questions) and on a 4-point scale *"less than 1", "1-3", "4-10", "more than 10"* (for the last question). A principal component analysis on the three variables indicated a single-component structure and the first component explained 77% of the total variance (eigenvalues: 2.32, 0.43, 0.25). We therefore computed an individual index of reading habits as the individual score on the first component.

Finally, an additional set of demographic covariates was collected, including participants' age, gender, nationality, and the main language spoken at home.

3.2.3.3. Analysis plan.

The first goal of the study was examining the psychometric properties of the adapted PMA-Verbal task. To this aim, we examined the structure of the measure using Item Response Theory (IRT). In our study, we selected the most parsimonious IRT model (among 1-PL, 2-PL, and 3-PL) according to the AIC (Akaike, 1974) and BIC (Schwarz, 1978) criteria. Furthermore, we inspected the limited- information M_2 fit statistic (Maydeu-Olivares & Joe, 2006). Since the M_2 NHST is sensitive to sample size, we evaluated model fit based on fit indices associated to M_2 (Maydeu-Olivares, 2015), for which similar criteria to those used in Structural Equation Models apply (Hu & Bentler, 1999; Maydeu-Olivares, 2015): Values of RMSEA and of SRMR lower than .05 and values of CFI and TLI larger than .90 indicate good model fit. We also tested potential misfit at the item level using the $S\text{-}X^2$ item fit statistic (Orlando & Thissen, 2000; Thissen & Orlando, 2003) with a Benjamini-Hochberg adjustment for multiple comparisons (Benjamini & Hochberg, 1995; Edelen & Reeve, 2007). A significant result indicates a rejection of the null hypothesis that an item's response pattern is consistent with the model (Ames & Penfield, 2015). We tested the unidimensionality assumption in two ways: First, we inspected whether the ratio of the first to the second eigenvalues of the tetrachoric correlation matrix was larger than three, as suggested by Morizot, Ainsworth and Riese (2007); second, we used the modified parallel analysis procedure suggested by Drasgow and Lissak (1983). We computed the parameters of the *Item Characteristic Curve* implied by the model for each item and examined the *Test Information Function* and the *Standard Error of Measurement*. We considered a value of the Standard Error of Measurement (SEM) lower than .54 (roughly corresponding, in classical test theory terms, to a Cronbach's alpha of .70) as a cutoff for good reliability of the ability estimates. IRT analysis was performed using packages *mirt* (Chalmers, 2012) and *ltm* (Rizopoulos, 2006) in the R statistical software (R Core Team, 2019).

In a second step, we used network analysis in the form of a Gaussian Graphical Model (Costantini et al., 2015, 2019; Epskamp, Borsboom, et al., 2018) to examine the mutual relationships among verbal ability, fluid intelligence, and characteristics of the adolescents' environment, as well as age and gender effects. A GGM is a model that encodes conditional dependencies and independencies among a set of variables: An edge between two nodes is drawn if they correlate after controlling for all other variables, whereas the absence of an edge among two variables means that they are independent after controlling for the others (Lauritzen, 1996). Edges can be thus simply interpreted as partial correlations. However, estimating a GGM by simply using maximum likelihood partial correlations has two drawbacks. First, absent edges are particularly informative in GGM, but exact zeroes are almost never observed in maximum likelihood estimates. Second, as the number of nodes increases, one can easily incur in overfitting (Babyak, 2004). We thus estimated the GGM using the Least Absolute Shrinkage and Selection Operator (lasso; Tibshirani, 1996) via the *graphical lasso* algorithm (Friedman et al., 2008). The *graphical lasso* consists in maximizing a penalized likelihood, with the amount of the penalty proportional to the sum of the absolute values of all parameters in the model (see also Danaher et al., 2014). This has the effect of excluding those partial correlations that, despite not being exactly equal to zero, are still small enough to be considered trivial. Such a procedure is routinely employed because it reduces the number of parameters to estimate, thus improving the reliability of the estimates, and produces a more conservative, sparser network, which is more straightforward to interpret[2]. The lasso regularization requires to select a parameter that regulates the amount of penalization. The regularization parameter was selected through the Extended Bayesian Information Criterion (EBIC; Chen & Chen, 2008; Foygel & Drton, 2010), as implemented in the R packages *bootnet* (Epskamp,

[2] A more detailed description of the graphical lasso rationale can be found Epskamp and colleagues (Epskamp, Borsboom, et al., 2018) and in Friedman, Hastie and Tibishirani (Friedman et al., 2008)

Borsboom, et al., 2018) and *qgraph* (Epskamp et al., 2012; Epskamp, Costantini, et al., 2018), using the default value of .50 for the EBIC hyperparameter. Furthermore, we employed the threshold parameter proposed by Jarnkova and van de Geer (2018), which further ensures specificity of edges.

After estimating the network, we examined the predictability of each node, which is the proportion of variance of the node shared with other nodes in the network and is useful to summarize the role of a node within the network (Haslbeck & Waldorp, 2017). The stability of the network results was inspected through confidence intervals obtained with nonparametric bootstrap. These confidence intervals cannot be used for testing whether edges are significantly different from zero, but only for comparing the weights of edges within the same network (Epskamp, Borsboom, et al., 2018). The stability of the predictability index was calculated using the *correlation stability coefficient* (*CS*- coefficient), which is defined as the maximum proportion of cases that can be dropped such that the resulting estimate correlates more than .70 with the original predictability estimate with 95% probability in case-dropping bootstrap resamples. Cutoff values of .25 and .50 have been suggested to indicate sufficient stability and good stability, respectively (Epskamp, Borsboom, et al., 2018).

3.3. Results

3.3.1. Psychometric Properties Of PMA

Table B2 reports the proportion of correct solutions for each PMA Verbal item. We decided to remove from further analyses item #2, which was solved by all participants but one and, therefore, did not have enough variance. Table 3.1 reports fit indices for the three IRT models considered. Both the AIC and the BIC indicated the 2PL model as the most parsimonious one. The 2PL model fit the data well, and all fit indices indicated that it provided a better fit to the data than both the 1PL and the 3PL models. We also compared the 2PL and the 3PL models using the Bayes Factor (Wagenmakers, 2007), which was clearly in favour of the 2PL model (*BF* = 1.62*10^41). This suggests that, despite the multiple-choice format of the test, guessing did not play an important role in the explanation of test scores. We thus focused on the 2PL model. The ratio of the first to the second eigenvalues was 5.63 and the modified parallel analysis converged in suggesting no significant violation of the unidimensionality assumption (p = .36). Item difficulty and discrimination parameters, item fit, and the proportion of correct responses for each item are reported in Table B2. None of the items showed a significant misfit. The item difficulty ranged between -6.19 (extremely easy item) and 1.42 (difficult item), with a prevalence of easy items. The items varied also in terms of discrimination, which ranged between 0.37 and 3.14. Figure 3.1

reports the Test Information Function and the conditional Standard Error as functions of ability (*theta*). The PMA-Verbal test showed a SEM < .54 in the ability range from -2.55 to 1.51, indicating a good performance in discriminating participants' ability in this range. For each participant, we computed ability estimates using the expected a-posteriori method (Kolen & Tong, 2010). It is worth noticing that the ability estimates showed sizable correlations with the simple count of correct responses by participants (*r* = .98, *p* < .001).

Table III.1 IRT Model comparisons

Model	N. par.	AIC	BIC	M_2	df	p	RMSEA [95% CI]	SRMSR	TLI	CFI
1PL	45	19411.48	19600.59	2009.13	945	< .001	.048 [.045, .051]	.091	.945	.945
2PL	88	18940.00	19309.82	1250.82	902	< .001	.028 [.024, .032]	.046	.981	.982
3PL	132	18944.86	19499.59	1223.96	858	< .001	.029 [.026, .033]	.049	.979	.981

Note. N. par. = number of free parameters

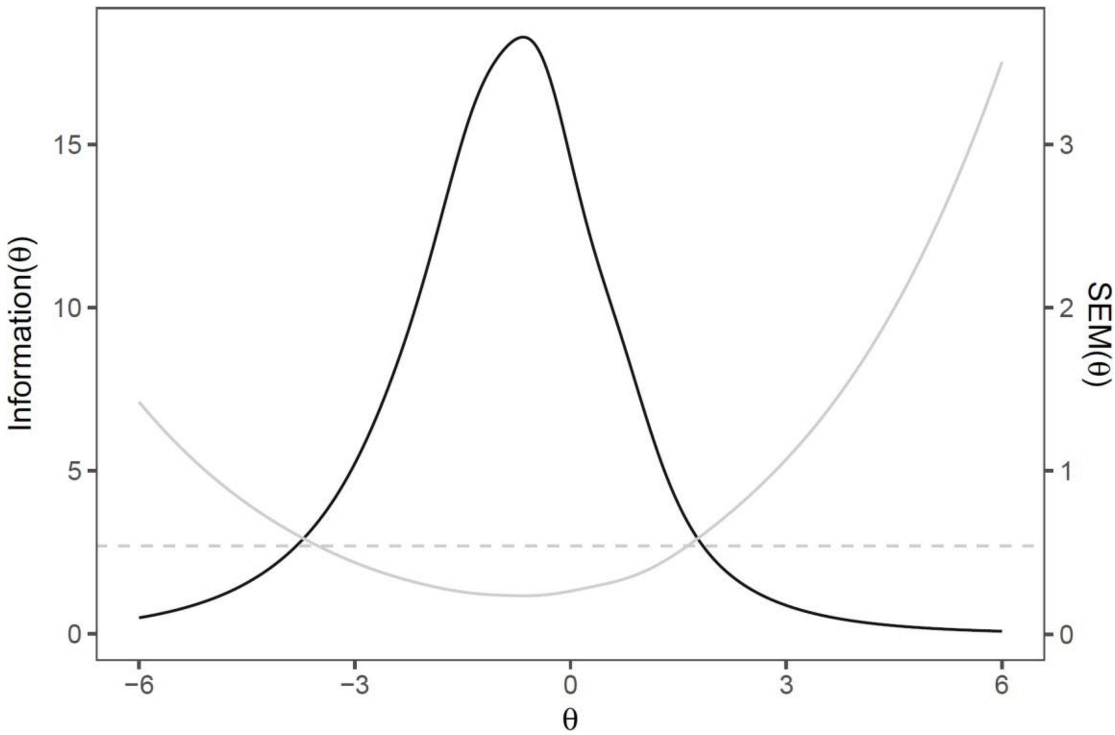

Figure III.1 Test information function and Standard Error of Measurement of the PMA-Verbal task.
Note. Test Information function = black line; SEM = gray line. The dashed horizontal line marks a SEM value of .54.

3.3.2. Network of Socio-Economic and Cultural Factors and Cognitive Abilities

Table 3.2 reports descriptive statistics and correlations for each of the variables considered in the network. We computed the network between PMA Verbal task, fluid intelligence, socio-economic and cultural indicators, age and gender. The final network is visualized in Figure 3.2, whereas exact values of each edge together with their bootstrapped confidence intervals are reported in Table 3.3. The network showed 16 nonzero edges out of 28 possible edges (57%), thus resulting relatively dense. The predictability index is also visualized in Figure 3.2 (for exact values see Table 3.2): The *CS*-coefficient for predictability was .89, indicating a remarkable stability for this index.

In the network, the three variables expressing the socio-economic and cultural environment (i.e., SES, Home Possessions, and Books at Home) were all interconnected, with the connection between SES and Books at Home being one of the strongest in the network. Notably, SES and Books at Home, but not home possessions, were also directly related to the PMA Verbal task. This suggests that home possessions might be relevant for vocabulary abilities only to the extent to which they are related to SES or to the books owned by a family. Interestingly, none of these variables was directly related to the Raven matrices, confirming that fluid intelligence is less dependent than crystallized intelligence on the family environment. Among socio-economic and cultural variables, only Books at Home was directly connected to reading habits. This indicates that the relationships between reading habits, SES and home possessions is strongly dependent on the number of books that are present in one's household. These results, together with the fact that Books at Home showed the second highest level of predictability in the network, are in support of the importance of the role played by the cultural capital for adolescents during development. Fluid intelligence, assessed through the Raven matrices,

was connected both to the PMA Verbal task and to Reading Habits. This may reflect the fact that fluid intelligence shapes active engagement in cultural activities, as well as crystallized abilities, but also the fact that reading habits and verbal abilities contribute to the development of fluid intelligence. Age related positively to both PMA and Raven matrices, indicating that older adolescents scored better in tests of crystallized as well as fluid intelligence. Interestingly, Age showed a significantly stronger relationship with PMA than with Raven matrices, as represented by the strongest edge in the network: this is coherent with the current views of experience and learning exerting a greater effect on crystallized rather than on fluid intelligence. After controlling for other variables in the network, Age resulted also negatively related to Reading habits, a finding which denotes how older adolescents in our sample engage less frequently in leisure (i.e., non-school related) reading. Finally, Gender ("0" for males, "1" for females) showed a negative association with Age, reflecting a higher proportion of females among younger participants in our sample. Gender was directly connected to PMA, highlighting a tendency of females to score better than males in the vocabulary task independently of all other variables considered, including Age. Such gender effect was not detected in the non-verbal reasoning task, as indicated by the absence of an edge connecting Gender and Raven matrices. The positive relationship between Gender and Reading Habits suggests that females are more likely than males to read in their spare time. Gender showed positive relations to Home Possessions as well. This might indicate that families with female offspring tend to have more Home Possessions, but it may also reflect a tendency of females to report higher scores in this question.

Table III.2 Network variables - descriptive statistics and correlations

Descriptive Statistics						Correlations						
	Mean	*SD*	*skew*	*kurtosis*	Pred.	1	2	3	4	5	6	7
1. Gender	0.50	0.50	-	-	.14							
2. Age	187.23	27.52	-0.17	-1.02	.34	-.06						
3. PMA-Verbal	0.00	0.95	-0.09	-0.67	.61	.24***	.50***					
4. SES	0.00	0.99	-0.22	-1.15	.52	.30***	.19***	.58***				
5. Home Possessions	8.40	1.63	-1.12	1.12	.32	.27***	.22***	.43***	.49***			
6. Books at Home	4.13	1.61	-0.35	-1.14	.58	.28***	.20***	.61***	.68***	.52***		
7. Reading Habits	0.00	1.00	0.39	-0.85	.29	.27***	-.01	.41***	.33***	.25***	.44***	
8. Raven	42.02	8.36	-0.75	0.33	.18	.07	.30***	.39***	.21***	.18***	.26***	.24***

Note. Gender was coded 0 for males and 1 for females. Pred = Predictability
* $p < .05$, ** $p < .01$, *** $p < .001$

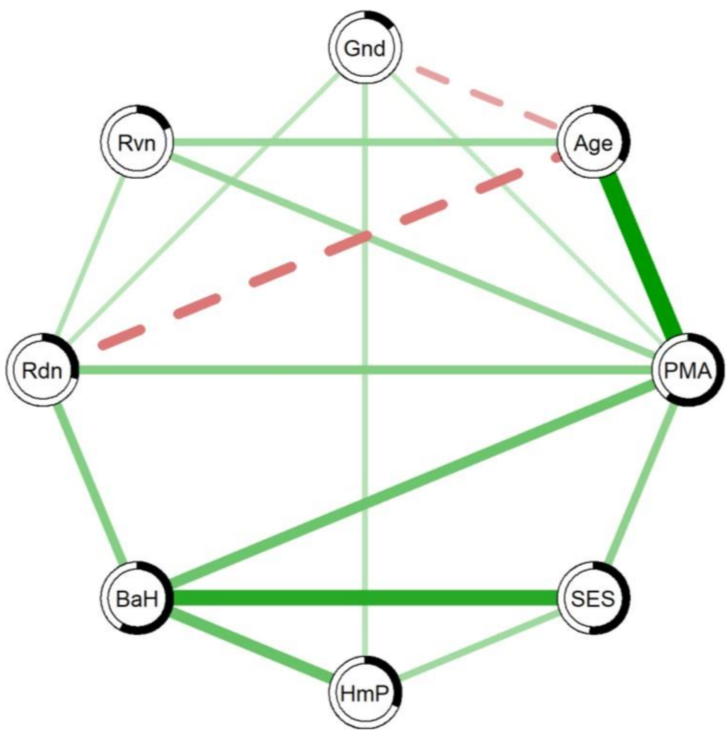

Figure III.2 Network model of intelligence, socioeconomic and cultural factors, reading habits, age and gender
Age, Gnd = Gender (females = 1 and males = 0), PMA = adapted Primary Mental Abilities Verbal task, SES = Socio-Economic Status, HmP = Home Posessions, BaH = Books at Home, Rdn = Reading Habits, Rvn = Raven Matrices.
The pie chart around each node represents its predictability. Dashed edges represent negative relationships.

Table III.3 Network edges with 95% boostrap confidence intervals, presented in order of size.

Edge	Value [95% boostrap CI]
Age – PMA	.45 [.36; .52]
SES – BaH	.38 [.30; .45]
HmP – BaH	.27 [.16; .36]
PMA – BaH	.26 [.18; .34]
Age – Rdn	-.24 [-.30; -.15]
PMA – Rdn	.22 [.13; .29]
BaH – Rdn	.22 [.13; .29]
PMA – SES	.20 [.09; .28]
Age – Rvn	.18 [.00; .26]
PMA – Rvn	.18 [.00; .26]
SES – HmP	.17 [.00; .25]
Gnd – Age	-.17 [-.24; .00]
Rdn – Rvn	.14 [.00; .23]
Gnd – HmP	.13 [.00; .20]
Gnd – Rdn	.12 [.00; .20]
Gnd – PMA	.11 [.00; .18]

Note. SES = Socio-Economic Status, BaH = Books at Home, PMA = Primary Mental Abilities Verbal task, Rdn = Reading Habits, HmP = Home Possessions, Rvn = Raven Matrices

3.4. Discussion

3.4.1. PMA Verbal

This study aimed at mapping and examining the relationships among cognitive (i.e., crystallized and fluid intelligence) and environmental factors in a group of Italian adolescents. In order to do so, we first adapted the original, paper and pencil Italian version of the PMA Verbal task, dating back to 1957, to a computerized format. The PMA Verbal task is a test of receptive knowledge, which requires the participant to access knowledge of word meaning and, as such, can be considered as a good measure of crystallized intelligence. The adapted PMA verbal resulted as a brief and simple instrument that can be administered and scored with ease even when dealing with large groups of participants. The IRT analysis confirmed the good psychometric properties of the test: despite the multiple-choice format, guessing did not significantly affect test scores. Further, all test items, with the sole exception of item #2, showed a uniform behaviour, none significantly misfitting the 2PL model. Finally, the low SE in a good range of ability levels makes the PMA Verbal reliable for the assessment of verbal ability in developing populations.

3.4.2. Network of Socio-Economic and Cultural Factors and Cognitive Abilities

For what concerns the study of the relationship between measures of crystallized and fluid intelligence, socio-economic status, home resources, attitudes towards culture (i.e., both personal and embedded in the family context), age and gender, we employed network analysis. In particular, we estimated a GGM tracing the pattern of associations among all variables considered, thus creating a comprehensive picture of the environmental and personal factors influencing the cognitive profile of an adolescent. It is important to keep in mind that relationships within a GGM network are conditional, as they are estimated *given all other elements of the system*. The adoption of such a model seems therefore extremely suited when the main interest is to examine the pattern of relationships among several potentially interrelated variables such as SES, Books at Home, home possessions, and intelligence. Crucially, our model highlighted not only associations, but also conditional independencies among variables: For instance, albeit we observed a significant bivariate correlation between Home Possession and Reading Habits ($r = 0.25$, $p < .001$), the relationships between these two variables became negligible in the GGM, after controlling for other variables in the network.

Overall, these findings corroborate the existing literature, showing that crystallized and fluid intelligence in adolescents are moderately correlated to each other (Schneider & McGrew, 2018) and differently associated with socio-cultural factors. Interestingly, the adapted PMA Verbal task showed a pattern of network connections consistent with the construct assessed, namely crystallized intelligence, thus confirming that receptive knowledge of word meaning may be considered representative of acquired knowledge (for application in cognitive assessments, see Flanagan & McDonough, 2018).

A graphical inspection of the Network model depicted in Figure 3.2 revealed a dense pattern of interconnections among context-dependent socio-economic and cultural resources. The pattern of relationships of Books at Home represents the most original finding of the present study: The bivariate associations between Books at Home, SES and Home Possessions are comparable to those recorded by previous research (Lipina et al., 2013; Rindermann et al., 2011; Sieben & Lechner, 2019; van Bergen et al., 2017), and in addition, our work brought into focus the conditional relationships among these variables. In particular, the Books at Home index was directly connected to PMA, even after controlling for SES, Reading Habits, and Home Possessions in the network. The Books at Home index estimates the number of books in a household. This index is taken as a proxy of the objectified cultural capital of an adolescent's family, which in turn has been shown to have a positive impact on life quality in adulthood, from both sociological and psychological standpoints (Sikora et al., 2019). The importance of cultural resources for educational and occupational attainment has been repeatedly confirmed by other research (Evans et al., 2010). More critically, recent studies have found an association between number of books in the household during adolescence and literacy/numeracy skills in adulthood, even when controlling for educational achievement and occupation (Sikora et al., 2019). Taken together, this evidence indicates that the Books at Home in early life seems to play a long-term and independent effect on cognitive functioning later in life, adding to the influence exerted by more common cultural indicators, such as educational achievement. Yet, all of these prior studies were based on adults, with the Books at Home index used retrospectively to estimate the size of participants' home library when they were 16. Our results provide further and novel insight on the short-term role of this index, as measured directly during childhood. In fact, to the best of our knowledge, very few studies have explored the unique contribution of a book-rich household to cognitive functioning at such a young age, differentiating it from other available resources, material, economic or social. Furthermore, the vast majority of these studies did not distinguish between fluid and crystallized intelligence (Flere et al., 2010; Guo & Harris, 2000; Luster & Dubow, 1992; Rindermann et al., 2011). Overall, our results confirm the unique and independent effect of Books at Home in cognitive development in youth, while at the same time displaying the close relation they share with social and economic factors. This encourages a more detailed view of social, cultural and economic background in order to gain a deeper understanding of their developmental influences on cognitive functioning.

Another interesting pattern that deserves further discussion is the unique relationship between books at home and reading habits. The positive association of reading activity to verbal abilities is well known in the literature (e.g., Stanovich, 1993, 1998) and, as mentioned above, recent studies on the effects of books in the household are pointing in the same direction (Evans et al., 2010). To our knowledge, no research has so far reported the conditional dependencies between reading habits and books at home given other elements such as home possessions, SES, and fluid and crystallized cognitive abilities. However, we reasoned that targeting the role of personal initiative in a sample of adolescents, for whom the family influence is gradually being complemented by the growing importance of personal choices, may result in a deeper understanding of their intellectual functioning. Consistent with this idea, we found that in our sample, reading habits and books at home were independently associated to crystallized intelligence. While the direct effects of reading habits on verbal abilities are straightforward to picture, the benefits apported by the books at home (i.e., independently of whether they are being read or not) may appear less intuitive. For this reason, we highlight that the Books at Home index is meant to be a proxy of the cultural resources offered by the familial context. These include not only actual reading material (i.e. books), but also a less tangible cultural capital consisting of experiences, references, knowledge and habits (what has been also referred to as "Scholarly Culture"; Sikora et al., 2019). For instance, in a book-rich house, the ideas and the language expressed in books may find different ways of circulating, influencing daily family life: books' contents may spread into conversations, may be referenced in jokes and games, may contribute to plan a specific trip or to give rise to a family tradition. In any of these ways and more, the resources represented by books are made available to all family members, whether or not they have actually read the books in question (Evans et al., 2010). This is perhaps a core example of how, during adolescence, both family and personal cultural investment contribute to the network of verbal intelligence.

Considering fluid intelligence, the Raven's SPM score shows a correlational pattern that is in line with the literature, occupying a marginal position within the network. Fluid intelligence represents, in fact, domain-general cognitive abilities, which are not very sensitive to experience and knowledge on a specific topic. In lay terms, fluid intelligence is associated to reasoning and problem solving (Sternberg, 2015). In the modern CHC model, fluid intelligence is the ability to perceive relations and extract new knowledge from unfamiliar situations or to solve novel problems when previously learned information and schemes cannot be applied (Schneider & McGrew, 2018). For this reason, the weak correlations with socio-cultural measures (especially when compared to those of Crystallized intelligence) are not surprising. Differences in family's SES or cultural investment, indeed, seem to bear little weight in determining adolescents' fluid abilities. Rather, it is interesting to observe that the Raven test score shares a positive, albeit weak, correlation with reading habits. This is coherent with our view of reading habits as reflecting a specific facet of attitudes towards culture, closely related to individual characteristics rather than to the shared social context.

3.4.3. Limitations

In interpreting our results a few limitations need to be considered, which may also help guiding future research. Our adaptation of the PMA Verbal, while accurately assessing participants at an average or slightly-below average ability level (i.e., from -2.55 to +1.50 standard deviations from the mean), becomes less informative at the higher ends of the ability continuum. A future adaptation of the PMA test may consider including a few difficult contemporary words. Till then, other tests could be more appropriate for discriminating performance within high-ability populations.

Our study intended to be an exploration of a complex system of cognitive, socio-economic, and cultural variables in a very peculiar age such as adolescence. We were interested in the individual role played by each variable within this system and our set of chosen measures was of course far from being exhaustive. However, the variables in our model accounted for key aspects of cognition, cultural resources, and included main measures of SES. New research on this topic will nonetheless need to assume a wider perspective, expanding on both the range of cognitive abilities and of culture-related habits and attitudes, in order to provide a comprehensive scenario of the complex association between socio-cultural factors and cognitive functioning in adolescence. In relation to this, research involving Italian secondary school students ideally should take into account the type of high school attended, as this has been shown to be related to the performance in various cognitive tasks (e.g., OECD, 2016). Indeed, this issue might be particularly relevant when verbal abilities are concerned, since language knowledge is variably trained in different schools. For instance, some items in the PMA-Verbal may be better suited for assessing abilities connected to specific courses of studies (e.g., classical studies might prepare students to discern words with clear Latin or Greek roots). Further research is thus needed to examine the mutual interplay between the selection and attendance to specific types of Italian high schools and the socio-economic, cultural, and cognitive variables characterizing individual students.

In this study we focused on age-independent relations among constructs. Yet, adolescence is an age of transition, therefore it would be interesting to extend our results by examining also the networks representing within-subject contemporaneous and cross-lagged relationships among intelligence and socio-cultural factors. Our results suggest an intriguing pattern of relations at the between-subject level, which can be used to inform future studies that might take a longitudinal, within-subject approach to explore dynamic changes in time, from late childhood to adolescence, up to early adulthood.

Finally, network analyses are mainly explorative in nature. We already mentioned how future studies might involve larger or more diverse samples in order to increase the reliability of the estimates. Additionally, it would be appropriate to test the associations that emerged through this work by applying confirmatory analyses (e.g., in a SEM framework). The relatively large sample involved in the present study represents a good starting point to formulate testable hypotheses to this end.

3.5. Conclusion

In conclusion, this study highlights the complexity of environmental and personal factors that influence intellectual functioning in a developmental stage of such extraordinary transformations as adolescence, and in doing so also proposes the PMA Verbal as a reliable and practical instrument for assessing Crystallized Intelligence in group settings, filling a sensitive gap in cognitive development research. It is well known that family and home environment play a crucial role in the early years of development, providing, among other things, material and social resources, motivation, support, and building attitudes and habits which last throughout adult life. Often, in psychological research, practical demands of data-collection call for summarizing these factors in a few broad indicators. When a more specific measure is used, the choice generally falls upon indicators of social status and wealth, such as parental educational achievement, occupation, or income. The results presented in our study suggest the usefulness of an additional indicator, that is the books at home index, concerning family outlook on cultural matters. This indicator is not properly captured by other measures but has a meaningful impact on cognitive functioning in youth as well as in adulthood.

3.6. Acknowledgements

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IV. STUDY 3

Cognitive Reserve Potential: Capturing cognitive resilience capability in adolescence

4.1. Introduction

4.1.1. Cognitive Reserve (CR)

Reserve is a relatively recent and complex construct that helps to account for individual differences in cognition, function, or clinical manifestations in the face of physiological or pathologicalageing or brain injury (Stern et al., 2018). Although it has been argued that the concept of reserve should be extended to accommodate variation in healthy individuals' performance (Stern, 2002), its predictive value has been chiefly acknowledged with reference to neurological conditions, either of degenerative or traumatic origin (Bigler & Stern, 2015; Pettigrew & Soldan, 2019). Moreover, as the etymology of the term *reserve* suggests – something "kept back" or "saved up" – the concept remindsof the outcome of a long-standing accumulation that comes into play at the later stages of life. Yet, this storage process is clearly set up early in life and may contribute to individual differences in cognitive efficiency and resilience from a younger age. In fact, despite being largely overlooked and variably measured, there are references to the concept of reserve to explain the cognitive outcomes ofearly brain dysfunction (Donders & Kim, 2019; Ekmekci, 2017). The present work aims to address this issue by developing a tool for the early assessment of Cognitive Reserve in the adolescentpopulation.

Cognitive Reserve (CR), together with Brain Reserve (BR) and Brain Maintenance (BM), is one of the three proposed mechanisms of Reserve which are invoked to account for discrepancies between brain insult or pathology and its clinical expression (Stern et al., 2018). The peculiarity of CRis its focus on the functional dimension: CR is defined as the adaptability of cognitive processes that helps to explain individual differences in how the brain copes with damage or decline. It has long been observed that there is no strict direct correspondence between the severity of brain damage and the manifestation of cognitive or functional impairment. This discrepancy holds for degenerative pathologies such as Alzheimer's Disease (AD - Neuropathology Group MRC CFAS, 2001) and acute insults such as strokes or traumatic brain injuries (Scarmeas & Stern, 2003; Stern, 2002). In all cases, a given extent of brain damage can cause severe impairment in a person while having little clinical consequence on another. The theory underlying CR is that more extensive and adaptable cognitive resources can help individuals cope with brain damage or decline, thus minimizing their clinical manifestations.

4.1.2. CR as a Formative Construct

The cognitive resources that constitute CR are described in terms of efficiency, capacity, and flexibility of functional brain networks (i.e., networks of brain regions associated with performing a task) (Stern et al., 2018). Research aimed at identifying relevant brain networks and assessing individual differences in their expression is still limited, and direct measures of CR are rarely available. Thus, CR is most frequently estimated through indirect indicators. These indicators measure experiences, lifetime exposures, or innate characteristics that support the development of CR. The main proxies of CR found in the literature are education, occupation, engagement in social and leisure activities, and early/premorbid IQ (Nucci et al., 2012; Scarmeas & Stern, 2003; Stern et al., 2018; Valenzuela & Sachdev, 2006). Each of these factors has been shown to contribute uniquely to CR, and their protective effects against clinical manifestation of brain damage are additive (Scarmeas & Stern, 2003; Valenzuela & Sachdev, 2006).

We could say that, in a broad sense, CR is determined by the exposures we use to measure it: In other words, it is a *formative* construct. This definition is based on the relationship between a construct (i.e., a conceptual term, used to refer to a generally unobservable phenomenon of interest) and its measures (i.e., observed data related to the same phenomenon) and it has important methodological as well as theoretical implications (MacKenzie et al., 2005). Formative constructs can be said to be caused or determined by their measures, thus distinguishing them from reflective constructs, which have the opposite relationship and are the cause or explanation for their measures (Bollen & Lennox, 1991). The latter are much more common in social sciences and this has shaped common attitudes towards measurement. For instance, when dealing with a reflective construct, we expect its measures to be associated with each other, we look at internal consistency to assess its reliability, and we discard individual measures that do not corelate with the others (van Rooij et al., 2017). Intelligence can be an example of a reflective construct: In an extremely simplified manner, we expect IQ to determine cognitive test scores, we expect those scores to correlate, and we rely on indices such as Cronbach's alpha to inspect the internal validity of scales or test batteries. The same logic cannot be applied to formative constructs. In their case, in fact, measures don't just serve the function of quantifying an unobservable phenomenon: They also have a strong theoretical role, because they determine the nature of the construct (Bollen & Lennox, 1991). An example of formative construct is a generalized price index: The index does not determine the price of individual goods, but rather, our interpretation of it is shaped by the goods considered and by their price. When dealing with formative constructs, there's no expectation of correlations between measures, thus indices of internal consistency such as Cronbach's alpha can be misleading. On the other hand, measure selection should not be based exclusively on statistical considerations, because its effects reach into the theoretical discourse, influencing the very nature of the constructs being assessed (van Rooij et al., 2017).

The model of CR we propose in this study is slightly more complex than the examples above, and it has been defined as spurious (Edwards & Bagozzi, 2000): Our construct of interest (i.e., CR) isnot directly determined by the observed measures (i.e., individual answers to test items). Instead, they are indirectly related through intermediate constructs (e.g., sports practice, frequency of engagement in cultural activities, parental support in studying…), that can in turn be assessed as reflective constructs through specific questionnaire items. We assume that several subordinate latent constructs capturing attitudes and habits determine the answers to test items, on the one hand, and shape global CR as a formative construct on the other (Figure 4.1).

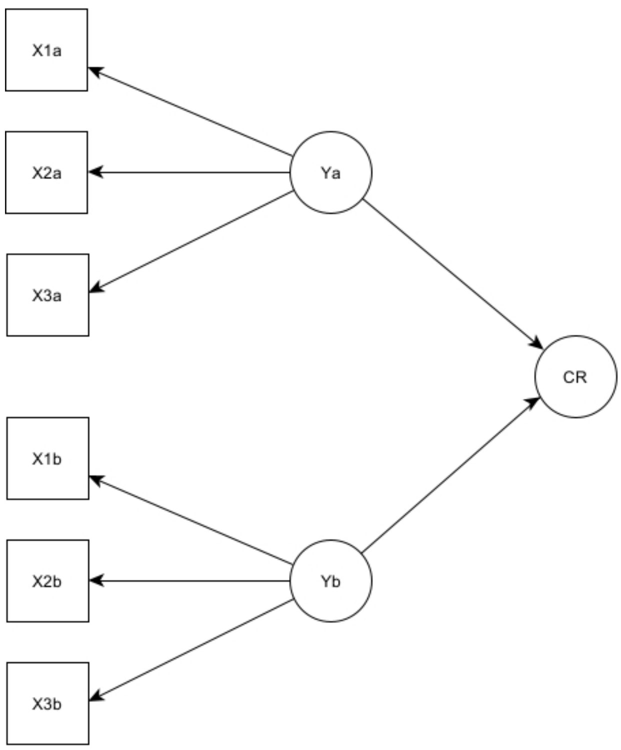

Figure IV.1 CR measurement model
Schematic illustration of the reflective and formative processes underlying the covariance between CR and the observed manifestations. Xij is due to intermediate reflective constructs Yj

4.1.3. CR in Youth: Cognitive Reserve Potential

CR has been studied mainly in adult – and especially in elderly – populations who experience a progressive decline in brain health due to physiological ageing and age-associated pathologies (e.g., dementia, AD). For this reason, indicators of CR have been selected with adult participants in mind: They detect and assess those experiences *in the life of an adult* that are most relevant to cognitive functioning. There is a consensus that CR builds up over the life span through multiple exposures, among which early-life cognitive ability, education, occupation, and leisure activities (Stern et al., 2018). Thus, the assumption is that the CR of an individual captures the entirety of the life experiences empowering their cognitive system. Upon this assumption, as soon as a child is engaged in any formal or informal *learning* activities, from playing in kindergarten to practising sports or social interactions, they build cognitive resources that can remain available throughout the lifespan. Accordingly, we recognise this early capital as a crucial start-up or potential factor for CR. We address whether it is possible to detect, early in life, individual differences resulting from experiential and educational activities that, alongside biological and environmental factors, may boost an individual's cognitive reserve. In principle, we would look at this early measure as a latent capability for cognitive resilience or *Cognitive Reserve Potential*.

Young populations are not immune to brain damage – of a traumatic origin or associated with a variety of neurological pathologies – and in these cases, as for adults, CR can have a significant influence on cognitive outcomes. However, indicators developed for adults are not always appropriate for use on youth (Kesler et al., 2010). Suffice to think that years of education and type of occupation, two of the main proxies of CR in adults, have close to no variability among adolescents who are yet to complete their formal education. This issue, of course, does not depend on age itself as much as on the kind of experiences associated with specific periods of life in different societies. Since indirect proxies of CR are often experiential in nature, we need somehow to consider individual differences in experiences.

Studies of CR in youth have focused primarily on children and adolescents with TBI (Donders & Kim, 2019; Fay et al., 2010; Karver et al., 2014), Paediatric Acute Lymphoblastic Leukaemia (Kesler et al., 2010) or Paediatric-onset Multiple Sclerosis (Ekmekci, 2017; Hosseini et al., 2014; Pastò et al., 2016). Cognitive ability is the single most used proxy of CR in youth, and it is often assessed through comprehensive batteries that include tests of verbal ability, reasoning, memory, and speed of information processing, such as the WASI battery used by Hosseini et al. (Hosseini et al., 2014). Higher premorbid or baseline cognitive ability is taken as an indicator of *better* (i.e., more efficient, or adaptable) cognitive processes, and therefore higher CR. Another indicator specific to studies on children and not used on adults is parental (and more often, maternal) education. Parental education has a double informational valence: It reflects genetic endowment shared between parents and their offspring, and it is correlated to environmental enrichment, learning experiences and quality of childcare, all of which contribute to cognitive development (Kesler et al., 2010). It could be said that the single measure of parental education fulfils in the young population the roles that education, occupation and leisure activities measures fulfil in adults: that of capturing experiential correlates of CR. We believe that IQ and parental education, however meaningful, cannot be expected to capture a breadth of life exposures comparable to that considered in studies with adults, especially when assessing adolescents. There is, therefore, still a need to identify and validate appropriate tools to evaluate CR in youth, and this is the primary purpose of the present work.

Our approach was partly inspired by the Cognitive Reserve Index questionnaire (Nucci et al., 2012), the most recently developed measure of CR for adult life (age 18 and up). The CRIq assesses three domains: education, occupation, and leisure activities, and it produces a separate score for each,based on the type and duration of activities, together with a global score. These three domains have different onset and progress differently during the life span: Most frequently, education begins early in life, to be completed over a continuous time interval of variable length. On the other hand, working activities usually start once education is completed, in the early stage of adulthood, their duration and continuity depending on various social and personal factors. Finally, leisure activities may cover the entire lifespan; their length, intensity, and continuity vary depending on individual resources and lifestyle. Undoubtedly, these three domains are strongly interconnected and interdependent (e.g., educational level is strongly associated with occupation). However, they contribute without redundancy to the CR of an individual (Nucci et al., 2012).

CRIq's main strength is combining multiple CR indicators instead of focusing on a single aspect. We aimed to reproduce this feature in our Cognitive Reserve Potential Questionnaire (CRPq). Since the initial stages of instrument development, our goal was to capture as wide a range of experiences as possible. So, we proposed items assessing different aspects of school and classroom environment, peer relations in and out of school, sports, music (i.e., singing or playing and instrument), family habits (e.g., chores, having guests, paying visits to other households), creative, artistic, and cultural hobbies. Another aspect we considered is that, during adolescence, behaviours gradually transit from being influenced mainly by family and other environmental contingencies to being shapedby individual preferences and choices. For this reason, we took care to investigate both aspects of adolescents' family and social context and characteristics of their personal experience.

We already mentioned how cognitive abilities or specific environmental factors (e.g., parental education, SES) are often regarded as correlates of CR, especially in youth. In this work, we strived to connect our research for CR proxies grounded in life experiences with the existing knowledge on CR. We assessed a comprehensive range of cognitive ability, executive functions and demographic factorsand explored their relationship with our proposed socio-behavioural measure of CR.

The aims of this work were i) developing an instrument capable of assessing life experiences potentially associated with the early development of CR during adolescence; ii) examining the psychometric properties of the instrument in an independent sample; and iii) exploring the associations between CR, as assessed by the new instrument, and measures of cognitive and executive functioning,as well as of social, economic, and cultural status.

4.2. Study 3.1

Our first study consisted in developing and administering the first version of the CRP questionnaire for adolescents, and in performing an iterative item selection.

4.2.1. Methods

4.2.1.1. Participants.

The sample involved in this study is the same that took part in the Study 2: 585 middle and high school students recruited in Northern Italy (295 females, mean age = 15.4 years, range = 11.3 – 20 years, SD = 2.3 years).

4.2.1.2. Measures.

Participants completed the first version of the CRP questionnaire together with measures of cognitive ability, cultural and socioeconomic status. These latter were described and reported elsewhere to address distinct theoretical questions (Study 2).

CR questionnaire. The questionnaire was a self-report instrument of 91 items investigating attitudes and behaviours in four domains and 11 sub-domains: leisure activities (i.e., sports, music, cultural activities, creative activities); family environment (i.e., parental support in studying, family openness, charity, participation in house chores); peer relations (i.e., classroom atmosphere, sociableness); and lifestyle (i.e., diet). On 82 items, covering all sub-domains, participants were askedto express the frequency with which they experienced a proposed attitude/ behaviour on a 6-point frequency scale scored from 1 to 6 (“never”, “hardly ever”, “sometimes”, “often”, “almost always”, “always”). The sports and music sections used 4 additional questions each to collect more detailed information on the practice: Participants reported for how many years they practiced sport or playing an instrument or singing, whether they did so as amateurs or at a competitive level, how many times per week they practiced and the average duration of a practice session (see Appendix C, CRP questionnaire). One question asked participants to report the number of books read in the previous year (excluding schoolbooks) and had four answer options: “less than 1 book”, “1-3 books”, “4-10 books”, “more than 10 books”. The first 82 questions were presented in random order, whereas the four additional sport questions and the four additional music questions were presented at the end of the questionnaire, in the same order for all participants. A question assessing the number of books readin a year was presented as part of the demographic section of the instrument and was administered immediately after the Books at home index (see Study 2 for a detailed description).

4.2.1.3. Procedure.

Participants were recruited through their schools: upon agreement with school principals, researchers contacted students and their families and invited them to take part in the study. The large majority of participants were minors, and they were considered eligible to join the study only if their parents or guardians provided written informed consent.

The data collection procedure was digitalized. The CRP questionnaire for adolescents was presented in between the two cognitive ability tasks which were the object of the Study 2. The tasks were administered collectively to the members of each class in the same order. The researchers were present to introduce the study and to offer instructions, supervision, and support when required. Eachstudent completed the tasks individually on a PC or tablet.

The study was conducted in compliance with the regulations issued by the Ethics Committee of the University of Milano – Bicocca (protocol number 448) and with the Helsinki Declaration (World Medical Association, 2013).

4.2.1.4. Statistical analyses.

The objectives of this work were the preliminary exploration of the dimensions detected by the questionnaire and the selection of a subset of items. The analyses were performed on 91 questionnaireitems. Because we wanted to control for potential age and gender differences, prior to the analyses wepartialled out of all items scores the effects of age and gender. To do so, each score was entered as thedependent variable in a linear regression model with age and gender as predictors. The unstandardizedresiduals of these regressions were then saved as age- and gender-independent scores (for a similar method, see Nucci et al., 2012). We employed Parallel Analysis (Horn, 1965) to select the number oflatent dimensions which best represented the data, and Principal Component Analysis (PCA) to explore how the items could be summarized by a limited number of dimensions. To obtain a subset ofitems which could maximize the parsimony and accuracy of the questionnaire, we excluded some items with high cross-loadings or with no substantial loadings (i.e., no loading ≥ 0.20) through an iterative procedure, running new analyses after the removal of each item. The *component scores* estimated through the PCA were used as individual scores in further analyses.

Analyses were performed in the R environment (R Core Team, 2020) using package *psych* (Revelle, 2020).

4.2.2. Results.

4.2.2.1. Item selection.

The list of questionnaire items and their descriptive statistics are reported in Appendix C, Table C1. The initial parallel analysis and scree plot (figure 1) on the full 91-items set (controlling for age and gender effects) both suggested the data was best represented by 13 components. We thus performed a PCA extracting 13 components with *oblimin* rotation. The component loadings of this initial PCA solution are presented in Table C2. Iterative item selection resulted in a final set of 69 items and a 12-components structure[3] (Table C3a). Upon examining the PCA component loadings, we interpreted these components as (in order): music experience, parental support in studying, cultural activities, participation in house chores, family openness, classroom atmosphere, substance use, sports, sociableness, charity, diet, and creative activities. These components were a close match to the 11 dimensions we had planned to assess with the instrument. The most notable exception was the split of the *diet* dimension in two components, one targeting eating habits (i.e., diet), the second targeting consumption of smoke, alcohol, or other potentially harmful substances (i.e., substance use). The components showed small correlations (*r*s between .00 and .21) and together accounted for 49% of theobserved variance (Table C3b).

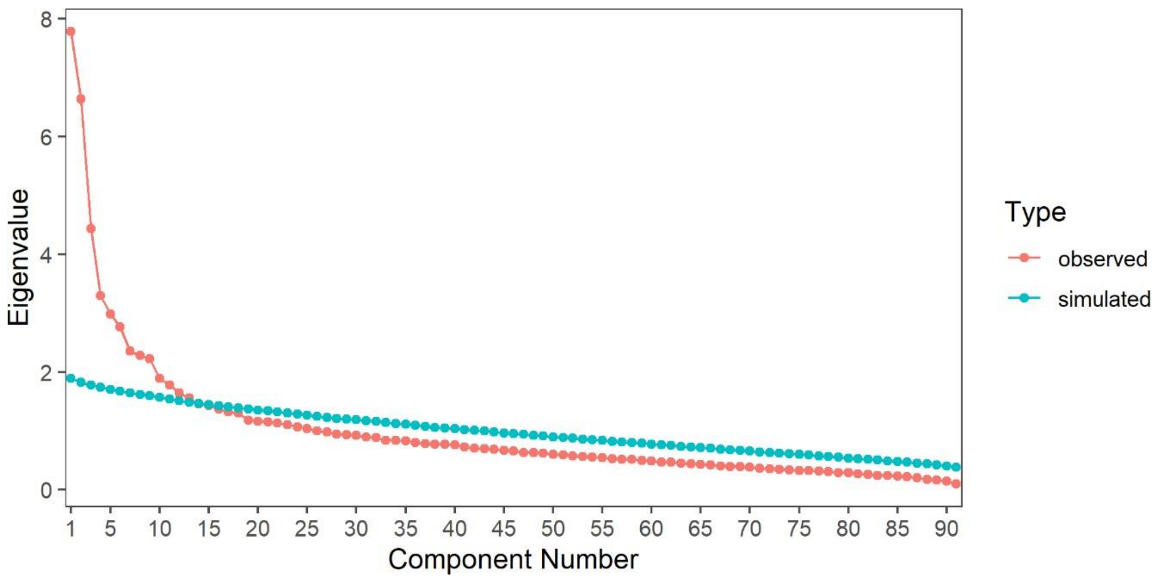

Figure IV.2 Scree plot of the parallel analysis performed on 91 questionnaire items

[3] The first 13 observed eigenvalues were: 6.144, 5.454, 4.037, 2.867, 2.567, 2.494, 2.250, 1.910, 1.729, 1.680, 1.673, 1.467, 1.320. The first 13 simulated eigenvalues were: 1.736, 1.680, 1.639 1.599, 1.561, 1.533, 1.508, 1.479, 1.452, 1.428, 1.403, 1.379, 1.362. One component consisted of only one item, plus secondary loadings by items that already had higher loadings on other components. After excluding items with sizeable cross- loadings, the 13th component was not recovered.

4.2.2.2. CR scales.

Eleven of the 12 scales (sports, music experience, cultural activities, creative activities, parental support in studying, family openness, charity, participation in house chores, classroom atmosphere, sociableness, diet) represented behaviours potentially beneficial to cognitive functioning and development, whereas the 12^{th} scale, substance use, coded a potentially harmful behaviour.

The twelve scales of the CRP questionnaire showed an overall good reliability, as assessed byCronbach's alpha: The average α was .74, with Sports and Music exhibiting the highest reliability (α = .82 for both scales), and Creative activities and Charity exhibiting the lowest (α = .57 and .66,respectively).

4.3. Study 3.2

In study 3.2, our goals were i) to test the holdout of the previously estimated model on a new, independent sample, and ii) to test how the factors assessed by the questionnaire related to measures of intelligence, socioeconomic and cultural factors, and executive functioning.

Both intelligence and socioeconomic factors are frequently used CR indexes. Particularly, pre-morbid IQ, albeit variably measured, has often been employed to estimate CR (Ekmekci, 2017). Yet, as previously pointed out, intelligence is undoubtedly related but not equivalent to CR and extremely high correlations between these indexes are neither expected not desirable (Nucci et al., 2012). In this study we assessed two broad facets of intelligence, i.e., fluid ad crystallised ability, through standard tests. We already described how socioeconomic/ cultural factors, especially maternal education, are among the main CR indicators in youth, as they are used to synthesize several facets of genetic and environmental endowment. Here we consider parental education and occupation, as well as family cultural resources, with indicators mutuated from sociological research.

Executive functioning (EF) tasks generally reflect the flexibility of cognitive strategies, the ability to quickly allocate cognitive resources (i.e., attention) where needed, and solve problems. By assessing the cumulative effects of life experiences, CR captures the coping capabilities of cognitive processes in the face of brain damage, such as enlisting alternative or compensatory strategies. Thus, the two constructs appear to share a close connection. Indeed, CR has been shown to correlate strongly with EF (Mitchell et al., 2012; Siedlecki et al., 2009). Hence, we included a battery of EF tests to explore their relationship with CRP in youth. EF refer to a complex multidimensional construct, and they require several measures to be estimated reliably. We combined a set of digitalized tasks to tap into some of the main EF components: attentional control, cognitive flexibility, information processing, and goal setting (Anderson, 2002).

4.3.1. Methods

4.3.1.1. Participants.

An initial sample of 379 high school students took part in this study. Students were recruited in three high schools in Northern Italy, in the provinces of Lodi and Varese. None of the participants had taken part in the research described in Study 3.1. Participants who did not complete the CRP Questionnaire, which was the main object of the present work, (n = 11) or who did not provide essential demographic information (i.e., age and sex; n = 17) were excluded from analyses. Analyses were thus performed on a sample of 351 participants (F = 201, mean age = 16.59 years, range = 14.42 – 20 years, SD = 1.04).

4.3.1.2. Measures.

CR questionnaire. The questionnaire used in this study consisted of the 69 items selected through the principal component analysis (PCA) in Study 3.1. As explained above, the items were structured on 12 scales: sports, music experience, cultural activities, creative activities, parental support in studying, family openness, charity, participation in house chores, classroom atmosphere, sociableness, diet, and substance use. These 69 items included 61 items scored on a 6-point frequency scale (“never”, “hardly ever”, “sometimes”, “often”, “almost always”, “always”), and the following eight additional items: Four items from the dedicated music experience section, three items from the dedicated sports section and the item “books read in a year” (for a detailed description, see the Methods section in Study 3.1). The fourth item from the sports section (i.e., “*Check each of the years in which you practiced sport as an amateur”)* was not used in the analyses but was kept in the questionnaire to preserve the symmetry between the Music experience and the sports sections.

Executive function assessment[4].

Arrow flanker task (adapted from Zelazo et al., 2013) The arrow flanker task was adopted to assesses selective attention and inhibitory mechanisms. The task required participants to respond as quickly as possible to an array of arrows presented on a computer monitor from a distance of 70 cm. Congruent and incongruent trials required participants to press a button corresponding to the direction of the central target arrow. Congruent trials consisted of an array of five arrows facing the

[4] All tasks were digitalised and run using Inquisit 5 software (Inquisit 5 [Computer software]. (2016). Retrieved from https://www.millisecond.com.).

same direction (e.g. >>>>> or <<<<<) and incongruent trials consisted of the four flanking arrows facing the opposite direction to that of the target arrow (e.g. >><>> or <<><<). Stimuli were preceded by a visual cue (1000 ms) and by a “middle” cue appearing in the same location as the central target arrow (1000 ms). Participants had 1750 ms to respond. The task consisted of three practice blocks with four trials each, followed by a test block with 40 trials. Administration of the test block was contingent upon a 75% of correct responses in the practice trials. The proportion of congruent and incongruent trials and left/right facing target was balanced throughout the task. The total duration was of four minutes. The variable of interest was the “congruency cost”: the difference between the mean response time in incongruent and congruent trials.

Symbol search task (WISC-V; Wechsler, 2014). A computerized version of the Symbol search task was adopted as a measure of information processing speed. Participants were presented rows of seven symbols: two symbols were presented to the left of a set of five symbols. The task required to verify, for each row, if the set of five symbols included either of the two symbols on the left. Participants answered by marking the matching symbol in the set of five or a “no match” checkbox, as appropriate. Their goal was to respond to as many items as possible within 2 min. The instructions included three practice items with feedback. The score was the number of correct responses minus the number of incorrect responses.

Wisconsin Card Sorting Task (WCST; Grant & Berg, 1948) A computerized version of the WCST was used to assess set-shifting or flexibility. The task required participants to discover and apply the correct criterion to sort two identical decks of 64 cards into four piles. The individual cards could be sorted on the basis either of the colour, the number, or the form of the figures appearing on them. Participants had to discover the adopted criterion by trial and error, receiving a positive or negative feedback every time they sorted a card into a pile. After 10 cards correctly sorted the criterion changed without warning, requiring participants to discover and apply a new one. Two parameters were considered when scoring the task: the number of categories (i.e., blocks of 10 cards sharing the same sorting criterion) completed, and the proportion of perseveration errors to the total number of errors. A perseveration error occurred when participants, after receiving a negative feedback on the categorization of a card, tried to apply the same criterion again.

Global-local task (adapted from Sjöwall et al., 2013) A modified version of the global-local task was used as index of attention switching. Stimuli consisted of Navon figures e.g., a large *global* circle (or square) composed by small *local* squares (or circles) – presented in the centre of the screen. In addition, a circle and a square appeared at the bottom of the screen at the same time as the Navon figure: Depending on their size (large or small), participants had to pay attention either to the global or to the local figures and identify the correct shape. The task consisted of three blocks:

the first two, presented in random order, consisted of 10 practice trials + 20 test trials each and presented a single condition (global for one block, local for the other). The third block, always presented last, consisted of 11 practice trials + 40 test trials. Within this “mixed” block the criterion was balanced and changed randomly in such a way as to present 50% of non-shift trials (which appliedthe same criterion of the preceding trial) and 50% of shift trials (which applied the opposite criterion from the preceding trial). Only the 40 test trials of the mixed block counted towards the scoring, whichwas based on the “shift cost”: the difference between the mean response time of shift and non-shift trials.

Tower of London (adapted from Krikorian et al., 1994; Shallice, 1982) This wasa planning task involving three balls that could be arranged in different configurations on three poles. Possible movements and arrangements were determined by a set of rules, and the goal was to move the balls from their starting position into a required configuration, using a predetermined number of moves. Completing the task required reproducing 12 configurations of increasing complexity that could be attempted a maximum of three times each. The task was preceded by one practice configuration. The final score was based on the number of configurations reproduced successfully and on the number of attempts required to do so (the maximum score was 36, for 12 successes on the first attempt).

Fluid and Crystallized intelligence

Primary Mental Abilities – Verbal task (Thurstone et al., 1957; α = .71). This was a synonym recognition task assessing receptive vocabulary knowledge, an indicator of crystallised intelligence. The task consisted of 45 target words, each accompanied by five answer options. Participants were asked to select the synonym of each target word from among the answer options (only one of the choices was correct), within a time limit of 7 minutes. The version of the task used in the present studywas adapted for digitalized administration to Italian students (Conte et al., 2020), for details on the rational and methods of the adaptation, see Study 2) . The score was the count of correct responses.

Raven abbreviated 9-item scale (Bilker et al., 2012; α = .54). A short version of the Raven Standard Progressive Matrices (Raven, 1941), consisting of a 9-item subset of the original matrices, was used as index of fluid intelligence. The score on this task consisted in the total of correct answers.

Academic achievement

Grades in Mathematics, Italian and English. Participants reported their mid-term grades in

Mathematics, Italian language and literature and English language and literature. Grades were on a scale from 1 to 10, with 6 being the minimum passing grade.

Socioeconomic and cultural factors

Socioeconomic Status (SES). (α = 0.64) SES was a composite score based on the educational achievement and occupational status of participants' parents, as reported by the participants themselves. Educational achievement was classified as one of five levels according to the International Standard Classification of Education (UNESCO Institute for Statistics, 2012): 1 = less than primary, 2 = primary, 3 = lower secondary, 4 = upper secondary, and 5 = tertiary. Occupational status was derived from participants' descriptions, which were used to determine the International Socio-Economic Index of occupational status (ISEI; Ganzeboom et al., 1992) for each parent. ISEI values ranged from 15 to 89, with higher values indicating higher occupational status. A parallel analysis on the ISCO and ISEI scores of both parents suggested a single-component structure. Standardized loadings on the first component ranged from .62 to .76 and the component explained 48% of the observed variance. We saved participants' score on the latent component as their SES index.

Books at home (OECD, 2013; Sieben & Lechner, 2019). A single-item index using a pictorial scale to assess the number of books present in a household. These are categorised as: "0–10 books", "11–25", "26–100", "101–200", "200–500", "more than 500 books".

Home possessions. We used a scale from the PISA 2015 study (OECD, 2016) to assess the presence in the household of 10 items of educational and cultural significance (e.g. educational software/ apps, a quiet room to study in, art pieces). The home possession score was the count of positive answers.

4.3.1.3. Procedure.

The recruitment of participants followed the same procedure described for Study 3.1. All the instruments were digitalized and administered in a single session. Participants completed the questionnaire and tasks on computers in a classroom setting. Researchers were present throughout data collection to explain the procedures and to assist when required.

To obtain information on a comprehensive set of cognitive abilities and executive functions without imposing excessive time and attention requirements, we opted for a planned missing data design (Graham et al., 2006): All participants completed the CRP questionnaire, the Arrow-flanker, Symbol search, and Wisconsin CST tasks, and the demographic section. In addition, each participant completed two of the remaining four tasks: Global-local, Tower of London, PMA verbal and Raven abbreviated scale. The CRP questionnaire was always presented first, followed by Arrow-flanker, Symbol search, and Wisconsin CST tasks in random order and by the demographic information section. The two final tasks and their relative order were randomized across participants. Table 4.1 summarizes the sample size for each combination of tasks.

Table IV.1 Valid and excluded observations in cognitive and EF tasks

Task	N	Valid	Outliers	Short RT	Other
Questionnaire	351	345			6[1]
Arrow Flanker	345	310	4	0	31[2]
Symbol Search	345	340	5		
Wisconsin CST	345	341	2		2[3]
Global-local	163	153	4	6	
Tower of London	164	162	2		
PMA Verbal	158	155	3		
Raven SPM	152	152	0		

Note. N = Number of participants who were administered the test. Outliers = number of participants whose scores on the task deviated more than 3 sd from the sample's mean. Short RT = Participants whose mean rt was shorter than 200 ms. [1]Two or more careless answers; [2] Did not pass practice trials; [3] Did not complete 1st category.

4.3.1.4. Statistical analyses.

Data quality.

Digitalized data collection is becoming increasingly common, due to the possibility of reaching a great number of participants, ensuring standard task presentation, and improving time efficiency. When using anonymous computerized procedures, however, careless responding can become a relevant concern (Meade & Craig, 2012). For this reason, we took steps to monitor the quality of our data. In the CRP questionnaire, we added three items designed to detect careless answers: these items were not related to the contents of the questionnaire, but simply instructed participants to mark a specific response to demonstrate that they were paying attention (e.g., "*To prove that you read this item, please answer 'never'*"). Participants who answered incorrectly to two or more of these items were excluded from the analyses. The arrow-flanker task included a practice phase, and participants who failed on 25% or more of the practice items were not presented with the task. In the arrow-flanker and in the global-local tasks, mean response times below 200 ms were discarded as unreliable. In the WCST, we used the number of completed categories as a verification variable: Failure to complete at least one category (i.e., failure to sort correctly at least 10 of the 128 cards) was taken as indicator of carelessness or of misunderstanding of the task requirements; therefore, participants with no completed categories were excluded from analyses involving this task. In all cognitive and executive function tasks, scores above or below 3 *SD* from the mean were considered outliers and removed from the analyses.

Validation of the CRP questionnaire for adolescents.

The first goal of this study was to validate the CRP questionnaire developed in Study 3.1. To do so, we tested the fit of the structural model identified in Study 3.1 on the new data with a Confirmatory Factor Analysis (CFA). Prior to the analysis, age- and sex- independent item scores were computed as the unstandardized residuals of the regression between raw item scores, age, and sex.

Association of CRP with intelligence, executive functions, and social, economic, and cultural factors.

The second goal of our study was to examine how CR, as captured by our questionnaire, correlated with participants' intelligence measures and executive functions, as well as with measures of social, economic, and cultural status. As in Study 3.1, CRP scales were identified based on the CFA model and *factor* scores were saved as individual scale scores. A global CRP score was computed as the sum of the 11 "beneficial scale" scores, minus the Substance use score.

We examined the psychometric properties of the scale scores in the sample and the pattern of bivariate correlations between global CRP score, scores on intelligence measures and executive function tasks, and measures of socioeconomic and cultural status.

Software, evaluation of model fit, and multiple comparison correction

The CFA model was estimated in the R environment (R Core Team, 2020) using package *lavaan* (Rosseel, 2012). We evaluated model fit based on the RMSEA, SRMR, CFI and TLI indices: RMSEA lower than .05, SRMR lower than .08, and CFI and TLI larger than .95 indicate good model fit (Hu & Bentler, 1999). The p-values for all associations of interest were corrected for multiple comparisons with Holm's method (Holm, 1979) using the *corr.test* function from package Psych (Revelle, 2020). Throughout the manuscript, we present standardised model estimates and the results marked as significant are those that survive Holm's correction.

4.3.2. Results

4.3.2.1. Data quality.

Table 4.1 summarizes the number of valid cases, outliers, and careless responses for each measure. Since the CRP questionnaire was the main measure of interest, participants who completed it carelessly were excluded from all other analyses (N= 6/351). Conversely, non-valid responses to one of the other tasks only warranted exclusion from analyses of that specific task. On average, we observed that 1.25% of the scores in cognitive and executive function tasks laid above or below 3 SD from the mean. Thirty-one participants did not pass the practice trials in the arrow flanker test, whereas only two failed to complete any category in the WCST. Six observations were excluded from the global-local task because of mean reaction times shorter than 200 ms.

4.3.2.2. Validation of the CRP questionnaire for adolescents

The 12-component model of CRP factors developed in Study 3.1 was fit on data from 345 participants. Model fit was acceptable: The SRMR (.067) was within the cut-off for acceptance, and the RMSEA was just above the threshold of .05. The null-model RMSEA was .103, thereby indicating that comparative fit indices such as CFI (.76) and TLI (.75) could not be interpreted as indicating lackof fit (Kenny, 2020).[5]

Table 4.2 reports reliability estimates and descriptive statistics for all scales and for global CRP, along with bivariate associations between scales. Similar to Study 3.1, scale reliability ranged between $\alpha = .60$ for Creative activities and $\alpha = .85$ for Music experience, with an average of $\alpha = .75$. Because we consider CRP to be a formative construct, internal consistency is not a meaningful measure of its validity, and we did not compute Cronbach's alpha for the global CRP score. Correlations among the scales were low to moderate, with the exception of those between sociableness and family openness ($r = .76$, $p < .001$) and between sociableness and classroom atmosphere ($r = .55$, $p < .001$). The charity and sociableness scales had the largest number of significant correlations with other scales, followed by parental support in studying and family openness. Charity, in particular, was positively associated with all other scales except sports and substance use. On the other hand, the music experience, sports, and creative activities scales, together with participation in house chores, share significant associations only with few (i.e., two or three) other scales. The large majority of the correlations we observed were positive. Significant negative correlations were found only between substance use and the cultural activities and diet scales (rs = -.18 and -.31, respectively, $p < .001$) and between cultural activities and sociableness ($r = -.31$, $p < .001$).

[5] Following a suggestion from the reviewers, we fit a hierarchical model with CRP as a second order factor. This model did not show a decisively better fit compared to the first order model: SRMR = .080, RMSEA = .053. AIC = 72843.71 and 73274.15 for the 1st and 2nd order model, respectively. BIC = 73631.63 and 73850.68 for the first and second model, respectively.
The fact that the hierarchical model did not offer an improved model-data fit is coherent with our characterization of CRP as a formative construct. In fact, formative constructs do not require shared variance among their indicators.

Table IV.2 Descriptive statics and bivariate correlations of CRP subscales and global score

	M (SD)	**skew**	**kurtosis**	**alpha**	**n. items**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1 Music exp.	0,00 (0,97)	1,71	1,72	0,85	6												
2 Parent Support	0,00 (1,12)	-0,79	0,34	0,83	7	.08											
3 Cultural act.	0,00 (1,22)	0,50	-0,31	0,73	6	**.27*** **	-.11*										
4 House Chores	0,00 (0,82)	-0,09	-0,35	0,74	7	.08	.00	.16**									
5 Family Openness	0,00 (0,53)	-0,25	-0,25	0,77	7	.02	**.20*** **	-.15**	.01								
6 Class Atmosphere	0,00 (0,66)	-0,40	0,20	0,79	8	-.11*	**.31*** **	-.07	.01	**.45*** **							
7 Substance use	0,00 (1,35)	1,14	0,24	0,84	5	.05	.05	**-.18*** **	-.06	**.32*** **	-.02						
8 Sport	0,00 (1,55)	-0,27	-1,23	0,80	4	.07	.07	.06	-.02	.08	.16**	-.09+					
9 Sociableness	0,00 (0,84)	-0,65	0,26	0,77	5	-.02	**.38*** **	**-.31*** **	.01	**.76*** **	**.55*** **	**.30*** **	**.20*** **				
10 Charity	0,00 (0,57)	0,54	0,23	0,70	5	**.33*** **	**.28*** **	**.25*** **	**.43*** **	**.24*** **	**.26*** **	-.03	.12*	**.33*** **			
11 Diet	0,00 (0,85)	-0,03	-0,09	0,62	4	.07	**.30*** **	.10+	**.19*** **	-.02	.08	**-.31*** **	**.36*** **	.13*	**.27*** **		
12 Creative act.	0,00 (0,76)	1,03	1,15	0,60	5	**.30*** **	.02	**.36*** **	.07	.07	-.13*	-.09+	-.08	-.06	**.37*** **	.01	
Global CR	0,00 (4,78)	-0,28	0,26	-	69	**.39*** **	**.45*** **	**.40*** **	**.33*** **	**.29*** **	**.40*** **	**-.33*** **	**.52*** **	**.38*** **	**.66*** **	**.59*** **	**.35*** **

Note. Pearson bivariate correlations. Stars denote unadjusted significance levels (+p ≤.01; *p ≤.05; **p ≤.01; ***p ≤.001). Bold typeface denotes Holm significant (q ≤.05); n items = number of items in the scale

The global CRP index ranged between – 15.53 and 12.00 (M = 0, SD = 4.78). Its associationswith individual scale scores ranged from r = .29 (family openness, p < .001) to r = .66 (charity, p < .001). Once again, this variability in item-total correlation is coherent with the formative nature of theconstruct.

4.3.2.3. Association of CRP with intelligence measures, executive functions, and social, economic, and cultural factors

In Table 4.3 we summarize the descriptive statistics of the executive functioning measures (Arrow-flanker, Symbol search, Wisconsin CST, Global-local and Tower of London tasks), of the cognitive ability measures (PMA-Verbal and abbreviated Raven matrices), of the self-reported school grades (for Italian, math, and English), and of the social, economic, and cultural status measures (SES, Home Possessions scale and Books at Home index).

Table IV.3 Descriptive statistics for measures of cognitive and executive functions, socioeconomic and cultural status, and school performance

Task	N	mean (SD)	skew	kurtosis
Arrow Flanker	310	39,49 (35,56)	0,02	1,34
Symbol Search	340	29,36 (7,75)	-0,25	0,22
Wisconsin CST	341	29,33 (18,19)	0,55	-0,39
Global - Local	153	65,20 (229,29)	0,02	1,35
Tower of London	162	26,73 (5,47)	-0,71	-0,08
PMA - Verbal	155	31,92 (4,74)	-0,45	0,19
Raven short	152	4,14 (1,82)	0,08	-0,84
SES	345	0,00 (1,00)	0,07	0,38
Home Possessions	345	8,22 (1,48)	-0,67	-0,32
Books at Home	345	3,50 (1,25)	0,09	-0,61
Grade italian	345	6,85 (0,95)	0,19	0,34
Grade math	345	6,64 (1,32)	0,65	-0,39
Grade english	345	6,88 (1,18)	0,16	-0,56

The mean score for Home Possessions was 8.22/10, indicating a good availability of material and culturally relevant resources. The least common possessions in the household were "educational app and software" and "[participant's] own room"; the most common were "a dictionary" and "[participant's] own desk". On average, participants reported a score of 3.5 on the Books at Home index, corresponding to a range of 26 – 200 books. The average grade was between 6.64 and 6.88 in all three subjects (i.e., Italian language and literature, Mathematics, and English language and literature).

Bivariate correlations among variables, with CRP, age, and sex are reported in table 4.4. Correlations were weak to moderate, and very few reached significance after adjusting for multiple comparisons. CRP was only associated with SES and Home Possessions: More home possessions and higher socioeconomic status corresponded to higher CRP (r = .23 and r = .22, respectively, p = < .001). The social, economic, and cultural measures correlated positively with each other (between $r = .26$ and $r = .36$, $p < .001$), as did grades in Italian, Mathematics and English (between $r = .24$ and $r = .44$, $p < .001$). A higher score in the abbreviated Raven matrices was significantly associated with a higher score in the Symbol search task ($r = .29$, $p < .001$), and had a strong association with higher scores in the Tower of London task ($r = .52$, $p < .001$), which approached significance even after the Holm correction, despite the relatively small sample size (N = 44). Notably, all scores were independent of both age and sex, and there were no significant associations between scores in CRP or in cognitive/ executive function tasks and indicators of social, economic, and cultural status.

Table IV.4 Bivariate correlations among CRP and measures of cognitive and executive functions, socioeconomic and cultural status, and school performance

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1 CRP	*345*	310	340	341	153	162	155	152	345	345	345	345	345	345	345	345
2 Arrow Flanker	-.01	*310*	306	306	138	148	140	141	310	310	310	310	310	310	310	310
3 Symbol Search	.04	-.04	*340*	336	151	161	153	149	340	340	340	340	340	340	340	340
4 Wisconsin CST	.01	-.06	.18**	*341*	151	159	154	151	341	341	341	341	341	341	341	341
5 Global - Local	-.06	-.24**	.03	.03	*153*	46	47	41	153	153	153	153	153	153	153	153
6 Tower of London	.00	.04	.21**	.12	-.06	*162*	44	42	162	162	162	162	162	162	162	162
7 PMA - Verbal	.00	-.08	.17*	.11	-.15	-.04	*155*	59	155	155	155	155	155	155	155	155
8 Raven short	.08	.00	**.29*** **	.23**	-.09	.52***	.16	*152*	152	152	152	152	152	152	152	152
9 SES	**.22*** **	-.08	.02	.00	.03	.06	.00	-.10	*345*	345	345	345	345	345	345	345
10 Home Possessions	**.23*** **	-.04	.04	.01	-.05	-.07	-.03	.13	**.26*** **	*345*	345	345	345	345	345	345
11 Books at Home	.14**	-.05	.06	.07	.00	.10	.16+	.10	**.36*** **	**.35*** **	*345*	345	345	345	345	345
12 Grade italian	.18**	-.05	.06	.04	.09	.04	.08	.12	.07	.12*	.11*	*345*	345	345	345	345
13 Grade math	.05	-.09	.09	.06	.14+	.13+	.12	.05	-.05	.04	.00	**.44*** **	*345*	345	345	345
14 Grade english	.11+	-.09	.08	.10+	.00	.18*	.19*	.25**	.01	.06	.09+	**.41*** **	**.24*** **	*345*	345	345
15 Age	.00	-.04	.10+	-.03	-.10	.03	.19*	.08	.04	.00	.16**	-.18***	.08	-.01	*345*	345
16 Sex	.00	.05	-.08	-.02	-.02	-.03	-.25**	-.07	.12*	.05	.05	-.05	-.08	-.15**	**-.18*** **	*345*

Note. Pearson bivariate correlations. Stars denote unadjusted significance levels (+p ≤.01; *p ≤.05; **p ≤.01; ***p ≤.001). Bold typeface denotes Holm significant (q ≤.05).Values on the diagonal (in italic) show sample size for each measure, values above the diagonal show sample size for each correlation.

4.4. General Discussion

4.4.1. Socio-Behavioural Indicators of CRP in Adolescence

The main aim of this work was to develop an instrument to measure socio-behavioural factors associated with CRP in adolescence. To our knowledge, socio-behavioural proxies of CR have all been modelled on adults, and they have limited use on youth. To fill this gap, we created a questionnaire collecting information on a wide variety of situations and experiences that are common in the life of Italian adolescents. By using PCA (in Study 3.1) we identified 12 CRP indicators: sports, music experience, cultural activities, creative activities, parental support in studying, family openness, charity, participation in house chores, classroom atmosphere, sociableness, diet, and substance use. The results from the CFA in study 3.2, performed on an independent sample, showed that this model fit the data well, thus confirming the factorial structure of the final CRP questionnaire.

Among the above-mentioned indicators, some are similar to those used on adult populations (e.g., sports, music experience, cultural and creative activities, charity); some are age-adjusted adaptations of dimensions commonly assessed in adults (e.g., the CRI-q measures *domestic chores* such as cooking, cleaning, grocery shopping; the CRP measures participation in house chores with items such as “keeping my room in order”, “making my bed”, “setting the table”); and others capture factors that are especially meaningful at a young age, compared to adulthood (e.g., parental support in studying, classroom atmosphere).

The dimensions established through the analyses were a close match to the areas we initially proposed to investigate: The only notable difference was the split of the Lifestyle area into Diet and Substance use. We hypothesized that eating habits, smoke, alcohol, and drug consumption would all be influenced by a general awareness of and care towards healthy behaviours. However, the observed distribution of questionnaire scores seems to suggest that, at least during adolescence, the approach to potentially “harmful” substances (i.e., smoke, alcohol, and drugs) and related behaviours is only weakly related to food choices ($r = -.31$, $p < .001$).

The good internal consistency (i.e., Cronbach’s alpha) and weak correlations among scales suggest that each of them reliably captured a well-defined area of experience, related to but not overlapping with the others. Consistently with this interpretation, the least internally consistent scale, in both studies, was creative activities ($\alpha = .59$ and $\alpha = .60$): Indeed, creative activities, despite sharing an aspect of content or material creation, included a diverse array of endeavours, ranging from photography to decoupage. The scales that had a broader range of correlations were those concerning relationships with others (i.e., parental support in studying, family openness, classroom atmosphere and sociableness). Attitudes and behaviours tended to be stable across social circles, and participants reporting availability and encouragement from their parents were also more likely to report that they enjoyed spending time with their peers and that they lived positive interactions in the classroom. One possible reason why these areas of experience appeared to have more numerous and stronger associations, compared to the other areas investigated, is that they capture habits that can be performed across occasions and situations, with peers in and out of school as well as with family members. On the other hand, scales such as music experience, sports or creative activities are focused on behaviours that are more likely to be mutually exclusive: Given the time and energy constrains that we all experience in our daily life, an extremely frequent or intense practice of a given activity (e.g., playing a sport or a musical instrument) is hardly compatible with an equally intense practice of a second or third activity.

As mentioned in the introduction, we consider CRP a formative construct: a composite score summarizing the breadth of exposures that could potentially promote the development of flexible and resilient cognitive processing from adolescence onwards. As such, high inter-scale correlations were not expected, nor especially desired. Rather, it was important to include several different dimensions, so as to capture all the different pathways through which children may develop their CRP.

4.4.2. Associations of CRP With Measures Of Intelligence, Executive Functioning, Academic Achievement, and Socioeconomic and Cultural Status

4.4.2.1. CRP and Intelligence.

The current study, to our knowledge, is the first using an experience-based measure to assess CRP on a sample of adolescents. Literature on socio-behavioural proxies of CR in adults has repeatedly shown that education, occupation, and leisure activities are associated with cognitive functioning in both the long and the short term (Opdebeeck et al., 2016). Nevertheless, our results revealed a remarkable absence of associations between intelligence measures and our CRP measure. There are several considerations to be made to this regard. First, the lack of published norms for either PMA- Verbal or Raven abbreviated scores prevents comparison with the reference population. However, the comparison of the PMA results from Study 3.2 with the results described in Study 2 (PMA validation study) reveals a significantly smaller variance in the former (Levene test = 56.013, p .001; SD (Study 3.2) = 4.74, SD (Study 2) = 7.99). Thus, the absence of CRP – PMA Verbal correlation could be explained partially by low variability within the sample. The same phenomenon could also explain the different correlation magnitude observed among PMA, SES, Home Possessions, and Books at Home in Study 3.2 and Study 2 (*r*s ≤ .16, and *r*s ≥ .43, respectively). The Raven abbreviated 9-item scale was only used in Study 3.2, so it was impossible to examine its scores in a similar comparative perspective as with the PMA-Verbal scores. A second consideration is that CR being a formative construct, the new indicators developed for CRP in youth may not follow the same pattern of associations as adult CR. This shift could be plausible given the difference in age and the timeframe relevant to the assessment. The CRP questionnaire refers to *current* behaviours and attitudes, i.e., typical around the time of the assessment. The only exceptions are sports and music experience, which consider years of practice in their measure. In contrast, the activities evaluated by the CRI-q can span up to several decades, depending on the respondent's age.

4.4.2.2. CRP and EF.

Contrary to our expectation, there were no significant correlations between global CRP score and measures of executive functioning. This finding is at odds with the literature, which has shown strong correlations between CR and EF (e.g., Mitchell et al., 2012), even seeing them as partially overlapping (Siedlecki et al., 2009). A critical difference in our study was the method for assessing EF: We used computerized testing in a group setting, whereas most previous studies measured EF individually, either through paper-and-pencil tasks or digitally. Digitalized grouped administration is still relatively rare, and additional research is needed to fully understand its impact. Also noteworthy, we observed only one significant association among EF tasks after correcting for multiple comparisons: Scores in the Symbol Search task and the Raven Abbreviated scale were positively correlated, as expected, given that they both rely strongly on visual analysis. Instead, several correlations among EF tasks were nominally significant but did not survive Holm's correction. Due to our planned missing data design, many of these bivariate correlations were based on small samples (i.e., as small as $N = 41$), which could explain why their significance dropped upon the correction. For instance, the correlation between the Tower of London and the Raven Abbreviated was the strongest detected in the study ($r = .52$, $p <.001$), but it was based on a sample of $N = 44$.

4.4.2.3. CRP and academic performance.

CRP was not significantly associated with the mid-term grades reported in either Italian, Mathematics or English after correcting for multiple comparisons. Still, the trend toward a correlation with Italian and English grades warrant further study. In this regard, although we deemed this measure of academic achievement appropriate within the scope of exploratory analysis, prospective investigations should also acknowledge the possible influence of teacher and school-related factors that were not considered in this study.

4.4.2.4. CRP and socioeconomic / cultural measures.

CRP was significantly and positively associated with SES and with the Home Possessions scale. These were the only significant associations detected for CRP in this sample of Italian adolescents. The association with the Books at Home index was nominally significant but comparatively weaker and did not survive Holm's correction. This association between CRP and socioeconomic/cultural measures was expected: CRP is an experience-based index and, although adolescence represents a turning point in the development of personal autonomy, the home and family environment (synthetically captured by SES, Home Possessions, and Books at Home) still have an undoubtedly strong influence. On the other hand, SES holds a peculiar status in this study, being the most common CR indicator in youth. The fact that it does not correlate with any cognitive measure in our sample should raise even more attention towards the results obtained from the intelligence and EF tasks.

4.4.3. Limitations

As mentioned above, this work raised a few key issues that should be addressed when planning future research on CRP. The first issue concerns the assessment of cognitive and executive function through group-administered computerized tasks. This method, though increasingly popular, is not as widespread as the more classical paper-and-pencil tests and the individual computerized tests. Its advantages (i.e., time efficiency, standard task presentation) are still offset by the scarcity of validated instruments and of population-based norms. This is especially true for EF tasks, some of which, relying on attention and speed, are more likely to be affected by the data-collection setting. Further research is needed to fully gauge the impact of the different methods and to provide test validation and normative data.

The second issue concerns sample features. While being far from small, study 3.2 sample was a convenience sample recruited in a setting – that of public high schools in suburban Lombardy – where social and demographic characteristics of students and families tend to be relatively uniform. Furthermore, the planned missing data design sensibly restricted sample size in some analyses. Based on the small-to-moderate effect sizes of the correlations between CRP and cognitive tasks, studying these phenomena adequately will require different sampling choices. Future work should look at ensuring greater diversity within the sample and larger baseline sample size.

4.5. General conclusion

We had the ambitious goal of detecting a single factor measuring the Cognitive Reserve Potential developed through life experiences in adolescence; an indicator to expand the representation of the resources available to youth in the face of brain insult or pathology and a starting point for adult CR. Our results suggest that we partly succeeded in this endeavour: We took the first fundamental steps in the development of a CRP questionnaire for adolescents, identifying relevant environmental and behavioural factors and assessing them consistently and reliably. Furthermore, the present work has allowed for a wide-ranging look at CRP in connection with cognitive abilities and executive functions, as well as for the analysis of the environmental factors that contribute to compose CRP itself.

Increasing diversity in the sample, recruiting participants from a wide range of social, economic, and cultural background, and exhibiting an equally wide range of cognitive and executive skills, will be key issues in future research. Secondly, progressing from an initial cross-sectional research to a longitudinal one will be a necessary step to shed much-needed light on the complex phenomenon of CR development in youth. Finally, the results collected here suggested that an experience-based measure of CRP shows small to modest correlations with measures of cognitive abilities in adolescence. Future studies are needed to investigate this relationship further and evaluate whether the cognitive and the experiential indicators of CR have mutual incremental validity in predicting relevant outcomes for the individual, for example in the reactions to brain insults or pathology.

V. CONCLUDING REMARKS

A starting point for the road ahead

5.1. General discussion

The overarching goal of this dissertation was to assess how personal experiences in youth shape lifetime cognitive trajectories – particularly, their impact on the development of Cognitive Reserve. Studies of CR in adults usually consider demographic, social, and behavioural variables (i.e., education, occupation, engagement in physical, social, or intellectual activities) as indirect CR proxies and examine them in conjunction with brain health and cognition. There is evidence that higher educational and occupational achievement and, to a lesser degree, engagement in cognitively stimulating activities, are associated with better cognitive functioning and lower incidence of dementia (Opdebeeck et al., 2016; Pettigrew & Soldan, 2019; Valenzuela & Sachdev, 2006). Additionally, measures of education and occupation appear to mediate the relationship between brain status and cognition (e.g., Chapko et al., 2018; Clare et al., 2017). A growing number of studies investigates CR as a predictor of cognitive outcomes in children with traumatic brain injury (Donders & Kim, 2019) or neuro-degenerative pathologies (Ekmekci, 2017; Kesler et al., 2010). These studies employ different kinds of predictors that reflect innate characteristics or environmental influences (e.g., childhood IQ, maternal education). However, we believe that including measures of personal experiences in CR assessment in youth could result in a more complete account of the phenomenon.

In this regard, we introduced the concept of Cognitive Reserve Potential (CRP): The latent capability for cognitive resilience in youth that results from experiential and educational activities, alongside biological and environmental factors. CRP constitutes a foundation for adult CR and improving our knowledge of it could have twofold advantages. On the one hand, the possibility to foster resilience against events – of a traumatic or pathological origin – compromising cognitive functioning in youth and early adulthood. On the other hand, given the “cumulative” nature of CR, promoting it from an early age could go a long way towards improving cognitive health throughout the entire lifespan.

The studies that we carried out have tackled this issue from various standpoints. In Study 1, taking up a longitudinal perspective, we studied the associations between the cognitive trajectories observed in different phases of life, namely, from childhood to late adulthood (age 11 to age 70) and from late adulthood to older age (age 70 to age 82). In Study 2, we looked at exposures to literary culture via the environment and individual activities (i.e., the number of books in the household and reading habits) to analyse their association with intelligence, over and above the effects of well-known socioeconomic factors. Finally, Study 3 aimed to develop a questionnaire to systematically assess the range of early experiences that we hypothesize could contribute to CRP.

The first of the three studies showed that, in a longitudinal birth cohort of 1091 individuals, earlier cognitive trajectories were indeed associated with cognitive change in old age. Individual differences in cognitive change between age 11 and 70 – measured on the same general ability test – significantly predicted individual differences in general cognitive ability change from age 70 to 82. Moreover, this association was independent of cognitive ability level in childhood and at age 70.

The results of this first study offer a broader perspective on cognitive development, directly linking earlier cognitive change with cognitive decline in older age. They also expand our understanding of cognitive change processes. Although this particular study did not focus explicitly on change mechanisms, the associations between trajectories at different ages suggest that some factors related to individual differences in cognitive change might operate over much of the adult life course, and certainly before older age. Several other studies in the field report similar conclusions. For instance, Salthouse's (2016) analysis based on a broad age range sample (i.e., from 18 to 80 years of age) found the stability, variability, and reliability of cognitive change to be remarkably consistent across adulthood. Such findings could imply that factors protecting against cognitive decline in older age may, in fact, successfully prevent or slow decline, beginning at a much younger age. On a different note, the idea that the benefits of favourable cognitive trajectories in early life may carry on across the lifespan also accords with life-course models of life experiences and cognitive abilities. These models highlight both the individual effects and the synergies between exposures encountered in different phases of life, from childhood to adulthood (Dekhtyar et al., 2015; Richards & Deary, 2005; Willis & Margrett, 2001). Finally, the association between earlier and later cognitive change independently of ability level is an example of differential preservation of cognitive abilities. This indicates that cognitive function in older age can be explained by different decline rates, alongside different peak levels of intelligence achieved in life (Salthouse, 2006; Salthouse et al., 1990).

As mentioned above, on the premise of continuity in cognitive change, correlates of cognitive ability in youth take on a double relevance. Early life exposures could affect cognitive health and well- being both in the short and in the long term, with important implications for strategies and interventions promoting successful ageing. Early life exposures investigated in cognitive change research frequently include perinatal and childhood health factors – such as birth weight, nutrition, height – and family or environmental resources – such as parental education, occupation, household features (e.g., Borenstein et al., 2006). However, other factors have shown promising associations with cognition.

In our second study, we focused on the impact of cultural resources, assessed by the number of books within the household (Books at Home index; Sieben & Lechner, 2019) and personal reading habits. We used network analysis to model the complex associations among cultural, demographic (i.e., age and gender), socioeconomic variables (i.e., SES, Home Possessions scale) and fluid and crystallised intelligence in a sample of 585 Italian adolescents. The comprehensive picture that emerged revealed that more Books at Home and more intense reading habits were associated with a higher level of crystallised intelligence, even when controlling for individual differences in age, gender, and socioeconomic status. Additionally, personal reading habits correlated positively with fluid intelligence, independently of all other variables in the model.

The reported positive associations among access to books, reading, and verbal ability (i.e., our measure of crystallised intelligence) are well-established in the psychological literature (Chateau & Jared, 2000; Cunningham & Stanovich, 1998; Sparks et al., 2014). The findings concerning the Books at Home index, specifically, are consistent with those obtained in other studies employing the instrument (Evans et al., 2010; Rindermann et al., 2011; Sikora et al., 2019). However, what makes these results especially meaningful is that the network model applied in the analyses estimates conditional relationships. This means that akin to partial correlations, associations between each pair of variables were independent of all the other variables within the network. In lay terms, such a model highlights how each of the factors considered contributes uniquely to the examined phenomenon. Therefore, detecting positive relationships between reading habits and intelligence measures reinforced our conviction that, even in youth, personal attitudes and experiences can play a significant role above and beyond family and environmental factors. To our knowledge, this was the first study to show that life experiences in adolescence, related to reading and book exposure, had an independent association with cognitive ability, beyond that accounted for by common demographic and socioeconomic indicators.

The findings of our second study are an example of how modelling selected personal experiences and environmental factors in youth can improve our understanding of cognitive function. In Study 3 we introduced Cognitive Reserve Potential (CRP) as a formative construct: A composite score indexing those resources, developed through childhood and adolescent experiences, that result in adaptable and resilient cognitive processes. In order to assess CRP, we developed a questionnaire investigating common experiences of Italian adolescents in four broad domains: leisure activities (i.e., sports, music, cultural activities, creative activities), family environment (i.e., parental support in studying, family openness, charity, participation in house chores), peer relations (i.e., classroom atmosphere, sociableness), and eating habits. Additionally, we explored the associations between estimated CRP and measures of intelligence, executive function, academic achievement, and socio- demographic factors.

Our results showed that the experiences captured by the CRP questionnaire pertain to 12 principal dimensions: sports, music experience, cultural activities, creative activities, parental support in studying, family openness, charity, participation in house chores, classroom atmosphere, sociableness, diet, and substance use. This 12-factor model showed a good fit to the data in confirmatory analyses performed on an independent sample.

Concerning the correlational analysis, the findings suggests that more extensive research would be required in order to map the relationship of CRP with intelligence and executive function. In fact, our global CRP estimate correlated positively with SES and Home possessions, indicating that higher socio-economic status and affluence favour a wide range of experiences in youth. However, we did not detect significant correlations of CRP with measures of intelligence and executive function, nor among individual cognitive and executive tasks. As discussed in detail in Study 3, these results could be partly explained by methodological issues, namely, the impact of computerized group testing, and the variability of socioeconomic and demographic factors within the sample. These issues shall both be addressed in future studies.

In conclusion, results from Study 3 indicate that the CRP questionnaire is a promising instrument, that can provide a reliable and consistent assessment of lifestyle factors in youth. This is the first requirement to analyse the CRP construct further, to test its validity and its place within a wider theoretical context.

5.2. General conclusion

The later stages of human life (i.e., from age 65 or 70 years onwards) constitute a major point of interest for research on cognitive change, because it is during those later years that people are exposed to greater risks of physiological and pathological cognitive decline (Santoni et al., 2015). The concept of Cognitive Reserve was also developed within the context of brain ageing and dementia. The intent was to explain individual differences in how cognition relates to brain health, and to capture what could broadly be considered cognitive resilience: the ability to preserve cognitive function in the face of brain damage.

The present work aimed at expanding the typical perspective by looking at mechanisms of cognitive change and cognitive resilience throughout the lifespan, with particular attention to youth. Indeed, intelligence and environmental conditions in childhood and adolescence are strong long-term predictors of life outcomes in adulthood (Brayne, 2007; Deary, Whiteman, et al., 2004; Sikora et al., 2019). Moreover, there is evidence to suggest a continuity in mechanisms of cognitive change across the lifespan: The processes governing cognitive decline in old age may be already in place at a much younger age (Craik & Bialystok, 2006; Salthouse, 2016).

The studies presented here show for the first time that cognitive change in early and mid-life (i.e., from age 11 to 70) is predictive of cognitive change rates from age 70 to 82. Such results emphasize the need to include children, adolescents and young adults in studies investigating cognitive change. We further showed that, during adolescence, personal life experiences can account for individual differences in cognition, over and above the effects of commonly considered factors such as parental education and occupation.

Future research in this field should aim at crafting a comprehensive picture of the factors that impact cognitive change and resilience in early life. This progress necessarily requires methodological and theoretical advancement. The final study in this dissertation introduced the notion of Cognitive Reserve Potential to refer to the life exposures potentially bolstering cognitive resilience in adolescence. In the same study, we also developed a reliable test to assess a wide range of such exposures.

This work represents just an initial step. Doubtlessly, more will need to be done as scientific progress allows us to deepen and refine our understanding of Reserve and of Cognitive Reserve in particular, for example in terms of functional brain measures. Nonetheless, we believe this first step can be instrumental and fruitful in fostering research along this path.

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VII. APPENDIX A

Supplementary material to Study 1

Cognitive change before old age (11 to 70) predicts cognitive change during old age (70 to 82)

7.1. Supplementary methods

7.1.1. Individual domain models

Separate cognitive measurement models were estimated for each of the three cognitive domains assessed, without any superordinate (i.e., general cognitive ability) factor. Each model included only data from the cognitive tasks relevant to the domain in question. LGCs were used to estimate task baseline level and slope parameters, and domain parameters were estimated as second-order factors. Cognitive change from age 11 to 70 (or NART-based measures of cognitive change where appropriate), sex and cognitive change × sex interaction were introduced as predictors of domain baseline level and slope.

Individual domain models were fit for each supplementary version of the main analysis, and results are collected in Table A5.

7.1.2. Raw difference score for cognitive change from 11 to 70 years

Raw cognitive change from age 11 to 70 was computed as the difference between MHT scores at Wave 1 (~70 years) and at the SMS1947 (~11 years). This change score's reliability was estimatedusing the method detailed in Johnson, Gow, Corley et al. (2012). We computed a Reliable Change Index (RCI) as the ratio of raw change between two time points (x_1 and x_2) to its standard error (SE):

$$RCI = \frac{(x_2 - x_1)}{SE_{diff}}$$

The standard error (SE) of the difference was computed as follows:

$$SE_{diff} = \sqrt{2SE_m^2} = \sqrt{2SD_1^2(1 - R_{xx})}$$

$$SE_m = SD_1\sqrt{(1 - R_{xx})}$$

where R_{xx} is the test-retest reliability. There is no published period-free reliability coefficient for the MHT instrument, so, based on its psychometric properties and correlation with the validated Stanford- Binet scale, we used an approximate value of .90, to indicate good reliability.

7.2. Supplementary results and tables

7.2.1. Model fit indices

This section reports fit indices for all the models tested in the present work.

The cognitive measurement models had an excellent fit to the data: comparative fit indices (CFI and TLI) were above .95, RMSEA was below .052 and SRMR below .06.

Regression models exhibited an equally good fit: CFI and TLI indices were close to or above .95 (The worse being Processing Speed modelled on the high-reliability subsample: CFI = .942 and TLI = .944). The RMSEA index value was ≤ .05 in all models. In contrast, SRMR seemed more sensitive to model complexity, with higher values for models estimating *g* and domain-specificabilities, and lower values for individual domain models.

Table A1 Model fit indices

Model	CFI	TLI	RMSEA	SRMR
Cognitive measurement models				
Bifactor	0.956	0.954	0.030	0.057
Visuospatial abilities	0.990	0.989	0.025	0.036
Verbal Memory	0.958	0.955	0.052	0.038
Processing Speed	0.955	0.952	0.050	0.055
Unadjusted regression models				
Residual 11-70 change				
g and domain-specific abilities	0.954	0.954	0.029	0.070
Visuospatial abilities	0.983	0.983	0.027	0.040
Verbal Memory	0.956	0.957	0.044	0.038
Processing Speed	0.947	0.947	0.046	0.058
Raw 11-70 change – full sample				
g and domain-specific abilities	0.954	0.954	0.029	0.055
Visuospatial abilities	0.985	0.985	0.025	0.035
Verbal Memory	0.955	0.956	0.044	0.037
Processing Speed	0.945	0.945	0.046	0.057
Raw 11-70 change – high reliability subsample				
g and domain-specific abilities	0.951	0.951	0.028	0.059
Visuospatial abilities	0.982	0.982	0.026	0.037
Verbal Memory	0.950	0.951	0.045	0.041
Processing Speed	0.942	0.944	0.045	0.063
Age-adjusted regression models				
Residual 11-70 change				
g and domain-specific abilities	0.952	0.953	0.027	0.063

Table A1 - Continued

Model	**CFI**	**TLI**	**RMSEA**	**SRMR**
NART-based regression models (unadjusted)				
Change from age 11 to NART				
g and domain-specific abilities	0.954	0.954	0.029	0.054
Visuospatial abilities	0.986	0.986	0.024	0.038
Verbal Memory	0.954	0.954	0.045	0.039
Processing Speed	0.946	0.947	0.046	0.056
Change from NART to age 70				
g and domain-specific abilities	0.954	0.954	0.029	0.082
Visuospatial abilities	0.985	0.985	0.025	0.040
Verbal Memory	0.955	0.955	0.044	0.039
Processing Speed	0.946	0.947	0.046	0.056

Note. Models are grouped by predictor and defined by their outcome measures (in italic). In all regression models: loadings, intercepts, and covariances previously estimated in the measurement models were fixed, whereas (residual) factor variances and regression coefficients were freely estimated. Age-adjusted models covaried task scores in Waves 1 through 5 with mean-centred age in days at each assessment.

7.2.2. Cognitive measurement model - factor loadings

Loadings on the first-order factors (i.e., task *baseline level* and *slope*) were identical across tasks. Observed scores had an unstandardized loading of 1.00 on the *baseline level* factor. The unstandardized loading on the *slope* factor depended on the assessment wave and expressed the time in years since Wave 1: λ = 0.00; 2.98; 6.75; 9.82; 12.54 respectively for Wave 1, 2, 3, 4, and 5.

Table A2 presents the standardized loadings of task parameters on second-order general and domain-specific factors.

Table A2 Cognitive measurement model's standardized factor loadings

	Second-order factor							
	Baseline level				Slope			
Observed Task	*g*	VIS	MEM	SPE	*g*	VIS	MEM	SPE
Matrix reasoning	0.787	0.252			0.831	-0.063		
Block design[1,2]	0.745	0.667			0.750	-0.661		
Spatial span[2]	0.768	0.049			0.957	-0.291		
Verbal paired associates[2]	0.441		0.647		0.637		0.771	
Logical memory	0.518		0.616		0.728		0.618	
Digit span backward	0.634		0.196		0.768		0.398	
Symbol search[2]	0.822			0.447	0.945			0.326
Digit-symbol substitution	0.624			0.601	0.899			0.127
Inspection time	0.544			0.282	0.922			0.241
Four-choice RT[2]	0.561			0.491	0.938			-0.346

Note. Loading of task parameters on general and relevant domain's parameters. g = general cognitive ability, VIS = visuospatial, MEM = verbal memory, SPE = processing speed.
[1] The residual variance of the baseline level parameter was fixed at 0
[2] The residual variance of the slope parameter was fixed at 0

7.2.3. Estimating cognitive change from 11 to 70 years as a raw difference score

Assuming an MHT reliability of .90, 69.75% of the sample showed a reliable change in scores (Wave 1 N = 761).

In the full-data models (Table A3, top), the raw difference predictor showed significant associations with *g* slope, but not baseline level. Participants exhibiting the greatest 11-70 improvement in MHT showed slower decline (β = 0.135. p = .002) in general cognitive ability. Regarding domain-specific abilities beyond *g*, greater 11-70 improvement corresponded to lower baseline level but slower decline of visuospatial ability, and lower baseline level of verbal memory.

When considering only participants who exhibited reliable cognitive change from 11 to 70 years (Table A3, bottom), the associations between age 11 to 70 change and *g* parameters resembled those described above. However, in these models, the effects did not survive FDR correction. Greater improvement between childhood and age 70 was significantly associated with lower domain-specific visuospatial ability at 70 years.

Table A3 Associations between raw 11-70 cognitive change and later-life trajectories of general and domain- specific[1] cognitive abilities

Effect	Baseline Level			Slope		
	β	C.I.	*p*	β	C.I.	*p*
Full sample						
g						
11-70 Change	-.052	[-.13, .02]	.178	**.135**	**[.05, .22]**	**.002**
Sex	**-.216**	**[-.29, -.15]**	**.000**	.090	[.01, .17]	.034
11-70 Change × Sex	.030	[-.04, .11]	.429	.026	[-.06, .11]	.548
Visuospatial Ability						
11-70 Change	**-.143**	**[-.23, -.05]**	**.002**	**.221**	**[.38, .06]**	**.007**
Sex	-.081	[-.17, .01]	.067	.110	[.27, -.05]	.187
11-70 Change × Sex	-.015	[-.10, .08]	.749	-.125	[.04, -.29]	.139
Verbal Memory						
11-70 Change	**-.104**	**[-.19, -.02]**	**.015**	.069	[-.04, .18]	.213
Sex	**.349**	**[.28, .42]**	**.000**	.039	[-.07, .14]	.464
11-70 Change × Sex	-.060	[-.14, .02]	.156	.053	[-.06, .16]	.338
Processing Speed[2]						
11-70 Change	-.042	[-.13, .05]	.348	-.031	[-.19, .13]	.704
Sex	**.362**	**[.29, .44]**	**.000**	-.104	[-.25, .04]	.169
11-70 Change × Sex	-.018	[-.10, .07]	.692	-.009	[-.16, .15]	.908
High-reliability subsample						
g						
11-70 Change	-.096	[-0.18, -0.01]	.033	.110	[.00, 0.22]	.045
Sex	**-.190**	**[-0.28, -0.1]**	**.000**	.091	[-0.01, 0.19]	.085
11-70 Change × Sex	-.049	[-0.14, 0.04]	.274	.049	[-0.06, 0.16]	.371
Visuospatial Ability						
11-70 Change	**-.140**	**[-0.24, -0.04]**	**.009**	0.166	[-0.01, 0.35]	.071
Sex	-.047	[-0.15, 0.06]	.384	0.051	[-0.13, 0.23]	.577
11-70 Change × Sex	-.026	[-0.13, 0.08]	.634	-0.120	[-0.3. 0.06]	.195
Verbal Memory						
11-70 Change	-.032	[-0.13, 0.06]	.513	-.036	[-0.17, 0.1]	.605
Sex	**.340**	**[0.26, 0.42]**	**.000**	.083	[-0.05, 0.21]	.211
11-70 Change × Sex	.016	[-0.08, 0.11]	.747	-.014	[-0.15, 0.12]	.833
Processing Speed						
11-70 Change	-0.040	[-0.14, 0.06]	0.432	-0.161	[-0.36, 0.04]	.109
Sex	**0.412**	**[0.33, 0.49]**	**0.000**	-0.011	[-0.21, 0.18]	.911
11-70 Change × Sex	-0.092	[-0.19, 0.01]	0.065	0.070	[-0.13, 0.27]	.494

Note. Standardized coefficients and p-values. *11-70 change* × sex = cognitive change from 11 to 70 × sex interaction; proportion of variance captured by domain-specific factors beyond *g*: visuospatial 17.5%, verbal memory 37.8%, processing speed 7.5%

[1] Domain-specific variance does not include general variance common to all tasks (captured by *g*)

[2] 4-choice RT task slope loaded negatively on the domain factor.

Bold typeface denotes p-values that survived FDR correction (q < 0.05).

7.2.4. Age-adjusted models

Table A4 Associations between 11-70 cognitive change and later-life trajectories of general and domain-specific[1] cognitive abilities, controlling for age differences at the time of assessments

Effect	Baseline Level			Slope		
	β	C.I.	*p*	β	C.I.	*p*
g						
11-70 Change	**.422**	**[.37, .48]**	**.000**	**.159**	**[.07, .25]**	**.001**
Sex	**-.149**	**[-.21, -.08]**	**.000**	.083	[.00, .17]	.048
11-70 Change × Sex	.077	[.01, .15]	.028	-.009	[-.10, .08]	.847
Visuospatial Ability						
11-70 Change	-.072	[-.16, .02]	.128	-.170	[-.35, .01]	.066
Sex	-.075	[-.16, .01]	.096	.089	[-.08, .25]	.288
11-70 Change × Sex	-.031	[-.12, .06]	.505	**-.229**	**[-.40, -.05]**	**.011**
Verbal Memory						
11-70 Change	.064	[-.02, .15]	.133	.122	[.01, .24]	.040
Sex	**.349**	**[.28, .42]**	**.000**	.051	[-.05, .15]	.332
11-70 Change × Sex	-.076	[-.16, .01]	.071	-.010	[-.13, .11]	.868
Processing Speed[2]						
11-70 Change	.011	[-.08, .10]	.802	-.165	[.33, .00]	.050
Sex	**.363**	**[.29, .44]**	**.000**	-.136	[-.28, .01]	.064
11-70 Change × Sex	-.095	[-.18, -.01]	.030	-.054	[-.22, .11]	.529

Note. Standardized coefficients and p-values. *11-70 change* × sex = cognitive change from 11 to 70 × sex interaction; proportion of variance captured by domain-specific factors beyond *g*: visuospatial 17.1%, verbal memory 38.7%, processing speed 7.9%

[1] Domain-specific variance does not include general variance common to all tasks (captured by *g*)

[2] 4-choice RT task slope loaded negatively on the domain factor.

Bold typeface denotes p-values that survived FDR correction (q < 0.05).

7.2.5. Individual domain models

Table A5 Associations between cognitive change from 11 to 70 years and later-life trajectories of individual cognitive domains

Effect	Baseline Level β	Baseline Level C.I.	Baseline Level *p*	Slope β	Slope C.I.	Slope *p*
Residual 11-70 change						
Visuospatial Ability						
11-70 Change	**.428**	**[.37, .48]**	**.000**	-.073	[-.22, .07]	.313
Sex	**-.166**	**[-.23, -.11]**	**.000**	.140	[.01, .27]	.028
11-70 Change × Sex	.074	[.01, .14]	.022	**-.200**	**[-.34, -.06]**	**.006**
Verbal Memory						
11-70 Change	**.369**	**[.30, .43]**	**.000**	**.198**	**[.10, .29]**	**.000**
Sex	**.178**	**[.11, .24]**	**.000**	.092	[.01, .18]	.035
11-70 Change × Sex	-.004	[-.08, .07]	.902	.011	[-.09, .11]	.829
Processing Speed						
11-70 Change	**.403**	**[.35, .46]**	**.000**	**.145**	**[.05, .24]**	**.004**
Sex	**.083**	**[.02, .14]**	**.008**	**.116**	**[.03, .20]**	**.009**
11-70 Change × Sex	.001	[-.06, .07]	.982	.005	[-.10, .10]	.928
Raw 11-70 change – full sample						
Visuospatial Ability						
11-70 Change	**-.092**	**[-.16, -.02]**	**.009**	.092	[-.04, .22]	.170
Sex	**-.221**	**[-.29, -.16]**	**.000**	**.143**	**[.02, .27]**	**.027**
11-70 Change × Sex	.037	[-.03, .11]	.289	-.093	[-.22, .04]	.159
Verbal Memory						
11-70 Change	**-.140**	**[-.21, -.07]**	**.000**	**.135**	**[.04, .23]**	**.004**
Sex	**.125**	**[.05, .20]**	**.001**	.092	[.00, .18]	.038
11-70 Change × Sex	-.028	[-.10, .05]	.452	.042	[-.05, .13]	.361
Processing Speed						
11-70 Change	-.064	[-.13, .01]	.072	.111	[.02, .20]	.018
Sex	.037	[-.03, .10]	.270	**.117**	**[.03, .20]**	**.008**
11-70 Change × Sex	.009	[-.06, .08]	.809	.005	[-.09, .10]	.913
Raw 11-70 change – high reliability subsample						
Visuospatial Ability						
11-70 Change	**-.144**	**[-0.22, -0.06]**	**.000**	.089	[-0.10, 0.28]	.368
Sex	**-.179**	**[-0.26, -0.10]**	**.000**	.103	[-0.05, 0.26]	.189
11-70 Change × Sex	-.036	[-0.12, 0.04]	.387	-.071	[-0.23, 0.09]	.380
Verbal Memory						
11-70 Change	-.106	[-0.19, -0.02]	.017	.036	[-0.07, 0.15]	.519
Sex	**.160**	**[0.07, 0.24]**	**.000**	.125	[0.02, 0.23]	.021
11-70 Change × Sex	-.020	[-0.11, 0.07]	.650	.018	[-0.09, 0.13]	.742
Processing Speed						
11-70 Change	**-.108**	**[-0.19, -0.03]**	**.007**	.058	[-0.06, 0.17]	.315
Sex	**.115**	**[0.04, 0.19]**	**.004**	.114	[0.01, 0.22]	.036
11-70 Change × Sex	**-.106**	**[-0.18, -0.03]**	**.008**	.030	[-0.08, 0.14]	.598

Table A5 - continued

Effect	Baseline Level β	C.I.	*p*	Slope β	C.I.	*p*
Change from age 11 MHT to NART						
Visuospatial Ability						
11-NART Change	**.202**	**[.14, .27]**	**.000**	-.013	[-.14, .11]	.839
Sex	**-.216**	**[-.28, -.15]**	**.000**	.135	[.01, .26]	.033
11-NART Change × *Sex*	.040	[-.03, .11]	.242	-.152	[-.28, -.02]	.019
Verbal Memory						
11-NART Change	**.300**	**[.23, .37]**	**.000**	.076	[-.01, .17]	.098
Sex	**.134**	**[.07, .20]**	**.000**	.072	[-.01, .16]	.102
11-NART Change × *Sex*	.022	[-.05, .09]	.554	-.007	[-.10, .08]	.880
Processing Speed						
11- NART Change	**.146**	**[.08, .21]**	**.000**	.081	[-.01, .17]	.078
Sex	.040	[-.03, .11]	.230	.101	[.01, .19]	.023
11-NART Change × *Sex*	-.001	[-.07, .07]	.986	-.016	[-.11, .07]	.725
Change from NART to age 70 MHT						
Visuospatial Ability						
NART-70 Change	**.484**	**[.43, .54]**	**.000**	-.128	[-.27, .01]	.071
Sex	**-.163**	**[-.22, -.10]**	**.000**	**.125**	**[.00, .25]**	**.051**
NART-70 Change × *Sex*	.064	[.00, .12]	.039	-.086	[-.22, .05]	.224
Verbal Memory						
NART-70 Change	**.367**	**[.30, .43]**	**.000**	**.131**	**[.04, .23]**	**.007**
Sex	**.175**	**[.11, .24]**	**.000**	**.085**	**[.00, .17]**	**.053**
NART-70 Change × *Sex*	.015	[-.05, .08]	.662	-.006	[-.10, .09]	.899
Processing Speed						
NART-70 Change	**.482**	**[.43, .53]**	**.000**	.046	[-.05, .14]	.357
Sex	**.088**	**[.03, .15]**	**.004**	**.107**	**[.02, .19]**	**.016**
NART-70 Change × *Sex*	.023	[-.04, .08]	.446	-.002	[-.10, .09]	.968

Note. Models are grouped by predictor. Standardized regression coefficients and p-values are reported. *11-70 change* × sex = cognitive change from 11 to 70 × sex interaction.
Bold typeface denotes p-values that survived FDR correction (q < 0.05).

VIII. APPENDIX B

Supplementary material to Study 2

Intellect is not that expensive: differential association of cultural and socioeconomic factors with crystallized intelligence in a sample of Italian adolescents

Table B1 PMA Verbal Items - frequency of appearance, familiarity rating and answer choices

Item	Target	Relative Frequency[a]	Familiarity[b]	Answer options				
1	Fecondo	1.71	3.04	Fellone	Vegetale	Innovatore	**Fertile**	Formale
2	Guardare	306.97	4.88	Alcoolizzare	Pulire	Arruffare	**Osservare**	Mascherare
3	Pascolare	0.57	3.57	**Brucare**	Vezzeggiare	Contraddire	Nitrire	Raddoppiare
4	Provenienza	6.56	4.31	Intermediario	Emigrazione	**Origine**	Conservazione	Allargamento
5	Porzione	7.39	4.38	Traffico	Processione	Rottura	Abbozzo	**Parte**
6	Definito	7.54	4.45	Ereditario	**Determinato**	Particolare	Attribuito	Formato
7	Concorrente	20.63	4.18	**Rivale**	Liquidatore	Distributore	Ladruncolo	Esportatore
8	Ammasso	1.11	3.80	Imbarazzo	**Cumulo**	Rassodamento	Fondale	Stele
9	Vacillante	0.11	3.24	Vigilante	Addicevole	Seccante	Sciancato	**Barcollante**
10	Massacro	11.30	3.94	Terriccio	Tranello	**Carneficina**	Perfidia	Spedizione
11	Fodero	< .01	2.76	**Guaina**	Faccetta	Cardine	Ghirlanda	Broccato
12	Maltrattare	2.67	4.08	Incapestrare	**Malmenare**	Inamidare	Sobbalzare	Dominare
13	Seme	16.10	4.13	**Germe**	Omogeneo	Bosco	Riserva	Micrologia
14	Traditore	0.84	4.20	Beone	Toracico	Tarchiato	Braccato	**Sleale**
15	Indulgenza	1.87	3.34	Riforma	Innocenza	Vedovanza	Disonore	**Clemenza**
16	Dannoso	8.32	4.34	Arido	Indisciplinato	Antipatico	Putrido	**Nocivo**
17	Imboscata	1.85	3.61	Intrigo	Chiocciola	Complimento	**Tranello**	Rotaia
18	Melanconico	0.60	4.19	**Triste**	Mediocre	Istruito	Vuoto	Ghiacciato
19	Infamia	1.09	3.51	Infiammazione	Rapsodia	Puerilità	Nocività	**Vergogna**
20	Spettro	5.90	3.47	**Fantasma**	Trofeo	Oculista	Pigmeo	Oracolo
21	Gioviale	0.55	2.84	Bestiale	**Allegro**	Chino	Urbano	Verbale
22	Migrazione	3.20	4.29	Incastro	Transazione	Penombra	Apparecchiature	**Esodo**
23	Approfondire	16.34	4.57	Agucchiare	Insinuarsi	Crescere	Allungarsi	**Scavare**
24	Cattedrale	8.93	3.96	Negozio	**Duomo**	Palco	Arringa	Membrana
25	Allacciare	3.29	4.54	Degradare	Quadrare	**Congiungere**	Incolonnare	Rilegare
26	Candore	3.15	2.79	Presunzione	Debilità	**Ingenuità**	Alternativa	Donnicciola
27	Convenzione	13.85	3.87	Fede	Pagamento	Trattenuta	**Contratto**	Impero
28	Vacante	0.89	2.98	Temporaneo	Garante	Ovoidale	**Libero**	Turbolento
29	Miscredente	0.01	2.81	**Ateo**	Xenofobo	Mercante	Balordo	Perentorio
30	Pascolo	1.87	3.56	Tonsura	Sfrondamento	Gergo	Fisco	**Prateria**
31	Illudere	17.18	4.40	Diffamare	Mummificare	Stagnare	**Ingannare**	Denigrare
32	Miscuglio	4.75	4.10	Demolizione	Sciame	Esaltazione	**Miscela**	Pinguedine
33	Discussione	58.73	4.57	Perorazione	Ragionamento	**Dibattito**	Obbiezione	Dissenso
34	Apatia	0.52	4.04	Opposizione	Paleografia	Obbrobrio	Antinomia	**Indolenza**
35	Baldoria	0.24	3.82	**Gozzoviglia**	Giambo	Snobismo	Claudicazione	Ghiottoneria
36	Circoscrivere	2.49	3.46	Succhiare	Consacrare	Estirpare	**Delimitare**	Graziare
37	Temporaneo	10.66	4.33	Pirico	Latente	Solecismo	Stimolo	**Transitorio**
38	Lunatico	0.52	4.28	Argentino	Furbo	Astronomico	**Capriccioso**	Lineare
39	Svalutare	0.37	3.78	Demeritare	Spesare	Commissionare	**Deprezzare**	Contravvenire
40	Larghezza	2.29	4.59	Penuria	Misura	Liberalità	**Ampiezza**	Paternità
41	Raggiro	0.88	3.37	**Imbroglio**	Strappata	Mozione	Zucca	Spira
42	Correggere	18.98	4.49	**Emendare**	Amnistiare	Compilare	Premunire	Riempire
43	Ammonire	10.40	3.64	Incalzare	Raccomandare	Congratulare	**Sgridare**	Ritorcere
44	Bucolico	NA	2.55	Polemico	Troglodita	Avicoltore	Parabolico	**Pastorale**
45	Celare	10.28	3.39	Truccare	**Nascondere**	Vigilare	Tacere	Incastonare
Excl	Mariuolo	0.01	1.57	Ornamento	**Birbante**	Aristocratico	Mecenate	Meticcio
Excl	Signoreggiare	0.01	1.87	Taglieggiare	**Dominare**	Sussultare	Rattizzare	Rimproverare
Excl	Sbrindellare	NA	2.23	Barrare	**Lacerare**	Abbronzare	Amareggiare	Incanalare
Excl	Grassare	NA	1.80	Pigolare	Spiare	Imbavagliare	Sottrarre	**Predare**
Excl	Pusillanime	< .01	2.10	Gengivale	**Pauroso**	Plausibile	Topografico	Curvilineo

Note. Correct answer in boldface. NA = word did not appear in the corpus. Excl. = item excluded from test
[a]Number of occurrences of a word in the corpus, corrected by the number and size of corpus sub-sections in which the word appears.
[b]Rated on a 5-point scale where 1 = *not at all familiar* and 5 = *extremely familiar*

Table B2 PMA Verbal - IRT parameters, item fit statistics and proportion of correct responses

Item	Difficulty	Discrimination	S - X^2 *df*	*p*	Prop. Correct
1	-1.61	2.21	12.3016	.801	.89
3	-1.90	1.29	21.9124	.748	.87
4	-3.35	1.23	15.448	.563	.97
5	-2.98	1.30	15.5913	.665	.96
6	-1.50	0.83	28.6530	.748	.75
7	-2.73	1.14	21.8620	.743	.93
8	-4.60	0.93	3.945	.748	.98
9	-1.11	1.85	28.0322	.665	.79
10	-1.59	2.03	13.4119	.851	.88
11	-1.42	1.05	23.4927	.801	.77
12	-3.51	0.51	45.5529	.381	.85
13	-1.17	0.63	31.9329	.743	.66
14	-6.19	0.37	27.4226	.743	.90
15	0.12	1.65	23.1622	.743	.47
16	-2.04	1.74	14.2618	.801	.92
17	-1.71	1.17	26.5327	.743	.83
18	-1.74	0.93	23.5629	.805	.80
19	1.42	0.54	33.0227	.665	.33
20	-2.53	1.07	22.9323	.743	.91
21	-0.98	1.42	30.7425	.665	.73
22	0.63	1.17	38.0423	.381	.36
23	0.46	0.61	28.3628	.743	.44
24	-2.36	2.07	8.378	.743	.96
25	-0.65	0.86	19.1927	.863	.62
26	0.02	1.20	23.8625	.748	.49
27	0.14	0.97	32.2427	.665	.47
28	0.45	0.83	22.2127	.801	.42
29	-0.70	1.52	22.7125	.748	.68
30	-1.36	1.05	34.5627	.665	.76
31	-1.19	1.97	31.1621	.625	.81
32	-1.29	2.85	16.5016	.743	.86
33	-1.13	2.52	16.5717	.743	.82
34	0.52	1.70	15.8120	.801	.36
35	0.05	1.50	31.5125	.665	.49
36	-0.67	2.25	14.8221	.851	.70
37	-0.26	2.22	24.3720	.665	.58
38	-0.35	1.76	33.0724	.665	.60
39	0.15	0.97	27.6227	.743	.47
40	-0.22	1.61	28.6324	.665	.56
41	-0.46	3.14	19.0716	.665	.65
42	1.40	0.99	38.2622	.381	.24
43	0.24	0.78	32.6428	.665	.46
44	0.68	2.88	11.4813	.748	.29
45	-0.35	2.93	22.4617	.665	.61

Supplementary material to Study 3:

Cognitive Reserve Potential: Capturing cognitive resilience capability in adolescence

9.1. CRP Questionnaire

9.1.1. Frequency-rated questions.

The following questions were all answered by reporting the frequency of the behaviour/ attitude on a scale from 1 to 6 (“*never*”, “*hardly ever*”, “sometimes”, “*often*”, “*almost always*”, “*always*”).

N.B. The questions, here divided by topic, were presented in random order to participants.

Shorthand	Question	CRP Scale (if retained)
Sports		
spo_agonism	Have you taken part in sport competitions or championships at a professional level?	sport
Music Experience		
mus_band	Do you play in a band?	music exp.
mus_recitals	How often do you take part in concerts or choir recitals?	music exp.
Cultural Activities		
cul_buying	Do you buy books, magazines or comic books?	cultural act.
cul_documentaries_r	When the cultural programmes on tv (e.g., documentaries) I change the channel	cultural act.
cul_museums	I visit museums and exhibitions	cultural act.
cul_reading	In you free time, do you buy books, magazines, or comic books?	cultural act.
cul_concerts	I go to concerts	
cul_concerts_r_r	I avoid listening to concerts	
cul_documentaries	Do you watch cultural programmes on tv or on the internet (e.g., news, documentaries)	
cul_museums_r_r	I avoid visiting museums or exhibitions if i have a choice	
cul_news_r	I do not follow the news	
cul_theatre	Do you go to the theatre?	
cul_workshops	Do you take part in cultural events (conferences, debates, workshops)?	
Creative Activities		
cre_decoupage	Do you decoupage or handcraft objects (e.g., jewellery, origami)?	creative act.
cre_exhibitions	Do you exhibit your work in exhibitions or contests (INCLUDING at school)?	creative act.
cre_film	Do you shoot movies/ shorts in your free time?	creative act.
cre_photos	Do you dedicate some of your free time to taking pictures, tweaking or archiving them (e.g. using specificsoftware)	creative act.
cre_share content	You upload contents of your own creation (e.g., texts, photos, music, videos, software) on a personal page or website	creative act.
cre_writing	Do you write poetry, stories or keep a diary (including blogs) in your free time?	cultural act.
cre_acting_r_r	I try to avoid acting	
cre_classes	Do you take classes of any artistic activity: acting, photography, drawing, video-making, decoupage, etc (EXCEPT dance, music or singing classes)?	
cre_drawing	Do you draw in you free time?	
cre_share _content_r	When I create something (e.g., writing, photos, music, video, etc.) I keep it to myself	

Shorthand	Question	CRP Scale (if retained)
Parental Support		
psup_ask_school	How often do your parents ask you about school?	Parental support
psup_aware	Are your parents aware of how you do in school?	Parental support
psup_care_homework	My parents care whether I do homework	Parental support
psup_confidence	My parents encourage me to believe in myself	Parental support
psup_encouragement	My parents encourage me to put effort in studying	Parental support
psup_help_difficulties	My parents help me if I have difficulties at school	Parental support
psup_help_homework	Do your parents help you with homework if you ask them	Parental support
Family Openness		
fam_guests_homework	How often do you have friends over to do homework together?	Family openness
fam_guests_meals	How often does your family have guests for lunch/dinner?	Family openness
fam_guests_night	How often does your family have guests staying the night?	Family openness
fam_guests_play	How often do you friends come to your house?	Family openness
fam_homework_out	How often do you go to your friends' house to dohomework?	family openness
fam_meals_out	Do you have meals at your friends' place?	Family openness
fam_night_out	Do you sleep over at your friends' house?	Family openness
fam_guests_r_r	I avoid inviting people at home	
fam_out_r_r	I avoid going to other people's houses	
Charity		
char_campaign	Are you part of a youth group organizing a campaign toraise awareness on an issue (including at school)?	Charity
char_community	Are you an active part or your community (e.g., raccolta differenziata, caring for green spaces, Sundays on foot)	Charity
char_funds	Do you take part in fundraisers or buy products tosupport charities?	charity
char_goods	Do you contribute to… donating objects (e.g., food, toys, clothes)?	charity
char_volunteer	How often do you participate in charity work as avolunteer?	charity
char_annoying_r	Do you find it annoying when volunteers try to elicityour support for a charity?	
char_marathons	Did you take part in sports or cultural events (e.g.,marathons, concerts) organized for charity?	
Participation in House Chores		
cho_bed	I make my own bed	house chores
cho_cleaning	I help with cleaning chores at home (e.g., sweeping, doing the laundry, hanging clothes to dry)	house chores
cho_cooking	Do you cook?	house chores
cho_insist_r	My relatives have to insist for me to do my chores	house chores
cho_room	Do you tidy up your room?	house chores
cho_someone_else_r	Someone else keeps my things clean and in order	house chores
cho_table	Do you set or clean the table?	house chores
cho_grocery	Do you shop for groceries for your family (even just a few items)?	
cho_look_after	Do you take care of other members of your family (e.g., siblings, grandparents)?	
Classroom Atmosphere		
cla_agreement	In my class we can reach an agreement to solve a problem	classroom atm.
cla_care	My classmates care about what I say	classroom atm.
cla_decisions	Teachers involve you and your companions in classroom decisions (re. e.g., breaks, homework)	classroom atm.

Shorthand	Question	CRP Scale (if retained)
cla_friends	I have many friends in my class	classroom atm.
cla_get_along_r	My classmates don't get along	classroom atm.
cla_group	I can work in a group together with my classmates	classroom atm.
cla_help_each_other	In my class we help each other out	classroom atm.
cla_ideas	I respect my classmates' ideas	classroom atm.
cla_sharing	I share my thing with my classmates	
Sociableness		
soc_company	When I have free time, I spend it in the company of others	sociableness
soc_company_r_r	In my free time I avoid the company of others	sociableness
soc_invited	I like when my friends invite me to join them in doing something	sociableness
soc_involve_others	When I do something that I like, I tend to get my friends involved	sociableness
soc_on_my_own_r	When I do something that I like, I tend to do it on my own	sociableness
soc_no_difference_r	Being alone or with others makes no difference to me	
soc_tv	Do you watch movies / entertainment with yourfriends?	
Lifestyle		
lst_fast_food_r	Do you eat fast food	diet
lst_healthy	I try to eat healthy food	diet
lst_vegetables_r_r	I avoid fruit and vegetables if I can	diet
lst_whatever_r	I eat whatever I want, without worrying about the effects on my health	diet
lst_alcohol	Do you drink alcoholic drinks?	substances
lst_harmful	Do you take harmful substances?	substances
lst_Sleep	Do you happen to sleep little at night	substances
lst_Smoke	Do you smoke (including e-cigarettes)?	substances
lst_Smoke_r_r	I avoid smoking	substances
alcohol_r_r	I avoid drinking alcoholic drinks	

9.1.2. Other formats: sports, music experience and cultural activities items

Shorthand	Question	CRP Scale (if retained)
Sports		
spo_day	When you play sports, how much time do you dedicate to this activity?	sport
spo_week	How many days per week do you play sports?	sport
spo_professional	For each school year, check whether you did not play sports, or played as an amateur, or at a competitive level	sport
spo_amateur	For each school year, check whether you did not play sports, or played as an amateur, or at a competitive level	
Music Experience		
mus_day	When you play or sing, how much time do you dedicate to this activity?	music exp.
mus_week	How many days per week do you practice playing or singing?	music exp.
mus_amateur	For each school year, check whether you did not play, or played as an amateur, or in a conservatory	music exp.
mus_professional	For each school year, check whether you did not play, or played as an amateur, or in a conservatory	music exp.
Cultural Activities		
cul_books_read	How many books did you read last year (EXCLUDING school books)?	cultural act.

9.2. Supplementary tables

Table C1 Descriptive statistics of CRP questionnaire items

Item (shorthand)	N	NA	mean	sd	min	max	skewness	kurtosis
Sports								
spo_agonism	584	1	3.41	1.81	1	6	0.12	-1.28
spo_day	585	0	2.48	1.33	0	4	-0.85	-0.46
spo_week	585	0	2.17	1.28	0	4	-0.47	-0.78
spo_professional	585	0	3.37	3.16	0	12	0.61	-0.61
spo_amateur	585	0	5.10	3.45	0	14	0.33	-0.66
Music Experience								
mus_band	584	1	1.38	1.10	1	6	3.11	8.87
mus_recitals	584	1	1.83	1.33	1	6	1.60	1.72
mus_day	585	0	0.70	1.11	0	4	1.43	0.91
mus_week	585	0	0.78	1.25	0	4	1.39	0.64
mus_amateur	585	0	2.26	2.91	0	13	1.21	0.71
mus_professional	585	0	0.31	1.11	0	9	4.24	19.78
Cultural Activities								
cul_buying	584	1	3.01	1.62	1	6	0.44	-0.85
cul_documentaries_r	584	1	3.86	1.44	1	6	-0.44	-0.66
cul_museums	584	1	2.79	1.31	1	6	0.51	-0.15
cul_reading	585	0	2.98	1.64	1	6	0.45	-0.89
cul_concerts	585	0	2.53	1.40	1	6	0.81	0.03
cul_concerts_r_r	585	0	4.11	1.80	1	6	-0.57	-1.07
cul_documentaries	585	0	3.35	1.40	1	6	0.24	-0.60
cul_museums_r_r	584	1	4.10	1.65	1	6	-0.54	-0.90
cul_news_r	584	1	4.36	1.24	1	6	-0.63	0.04
cul_theatre	585	0	2.41	1.27	1	6	0.69	-0.03
cul_workshops	585	0	1.86	1.13	1	6	1.49	2.10
cul_books_read	584	1	2.29	1.01	1	4	0.29	-1.01
Creative Activities								
cre_decoupage	584	1	1.74	1.26	1	6	1.84	2.72
cre_exhibitions	584	1	1.86	1.31	1	6	1.60	1.79
cre_film	585	0	1.51	1.11	1	6	2.48	5.78
cre_photos	585	0	2.44	1.41	1	6	0.85	-0.09
cre_share content	585	0	3.75	1.62	1	6	-0.28	-1.07
cre_writing	585	0	1.91	1.36	1	6	1.53	1.55
cre_acting_r_r	585	0	3.31	1.94	1	6	0.08	-1.56
cre_classes	584	1	1.81	1.50	1	6	1.81	2.00
cre_drawing	584	1	2.45	1.51	1	6	0.83	-0.27
cre_share _content_r	584	1	2.38	1.61	1	6	0.86	-0.48
Parental Support								
psup_ask_school	584	1	5.19	1.26	1	6	-1.62	1.89
psup_aware	584	1	5.43	1.07	1	6	-2.21	4.75
psup_care_homework	584	1	4.77	1.51	1	6	-1.00	-0.10
psup_confidence	584	1	4.94	1.36	1	6	-1.20	0.63
psup_encouragement	584	1	5.19	1.21	1	6	-1.54	1.78
psup_help_difficulties	585	0	4.54	1.55	1	6	-0.77	-0.51
psup_help_homework	585	0	4.12	1.66	1	6	-0.38	-1.07

Item (shorthand)	N	NA	mean	sd	min	max	skewness	kurtosis
Family Openness								
fam_guests_homework	584	1	2.55	1.14	1	6	0.45	-0.16
fam_guests_meals	585	0	3.20	1.01	1	6	0.39	0.39
fam_guests_night	584	1	2.19	1.08	1	6	0.92	0.83
fam_guests_play	585	0	3.51	1.23	1	6	0.03	-0.19
fam_homework_out	584	1	2.66	1.10	1	6	0.28	-0.26
fam_meals_out	585	0	3.77	1.06	1	6	0.29	0.09
fam_night_out	584	1	3.25	1.19	1	6	0.16	-0.01
fam_guests_r_r	585	0	5.01	1.17	1	6	-1.45	2.00
fam_out_r_r	585	0	5.10	1.02	1	6	-1.22	1.49
Charity								
char_campaign	584	1	2.54	1.45	1	6	0.76	-0.21
char_community	585	0	3.15	1.59	1	6	0.27	-0.99
char_funds	584	1	2.36	1.38	1	6	0.91	0.06
char_goods	585	0	2.90	1.39	1	6	0.45	-0.45
char_volunteer	584	1	2.10	1.25	1	6	1.27	1.35
char_annoying_r	584	1	4.22	1.42	1	6	-0.66	-0.18
char_events	585	0	2.76	1.41	1	6	0.48	-0.45
Participation in House Chores								
cho_bed	584	1	3.46	1.71	1	6	0.15	-1.24
cho_cleaning	584	1	3.47	1.41	1	6	0.19	-0.62
cho_cooking	584	1	3.30	1.35	1	6	0.19	-0.44
cho_insist_r	585	0	4.11	1.42	1	6	-0.55	-0.41
cho_room	584	1	3.97	1.40	1	6	-0.06	-0.82
cho_someone_else_r	584	1	3.17	1.57	1	6	0.20	-1.05
cho_table	584	1	4.28	1.42	1	6	-0.36	-0.85
cho_grocery	584	1	3.36	1.40	1	6	0.29	-0.62
cho_look_after	584	1	3.53	1.52	1	6	0.01	-0.84
Classroom Atmosphere								
cla_agreement	585	0	3.41	1.31	1	6	0.10	-0.61
cla_care	585	0	3.76	1.22	1	6	-0.16	-0.31
cla_decisions	584	1	3.92	1.32	1	6	-0.22	-0.55
cla_friends	584	1	4.83	1.35	1	6	-1.08	0.34
cla_get_along_r	584	1	4.20	1.07	1	6	-0.72	0.87
cla_group	585	0	4.37	1.34	1	6	-0.48	-0.61
cla_help_each_other	584	1	3.71	1.26	1	6	-0.01	-0.47
cla_ideas	584	1	4.32	1.24	1	6	-0.44	-0.36
cla_sharing	584	1	3.74	1.28	1	6	-0.05	-0.47
Sociableness								
soc_company	584	1	4.38	1.27	1	6	-0.50	-0.40
soc_company_r_r	584	1	5.06	1.16	1	6	-1.51	2.24
soc_invited	584	1	5.40	1.06	1	6	-1.99	3.72
soc_involve_others	584	1	4.06	1.25	1	6	-0.23	-0.38
soc_on_my_own_r	584	1	3.72	1.35	1	6	-0.39	-0.52
soc_no_difference_r	585	0	4.52	1.50	1	6	-0.90	-0.07
soc_tv	585	0	3.51	1.34	1	6	0.09	-0.53
Lifestyle								
lst_fast_food_r	585	0	4.21	1.12	1	6	-0.66	0.69

Item (shorthand)	N	NA	mean	sd	min	max	skewness	kurtosis
lst_healthy	584	1	4.12	1.32	1	6	-0.24	-0.62
lst_vegetables_r_r	584	1	4.98	1.32	1	6	-1.37	1.30
lst_whatever_r	584	1	4.22	1.47	1	6	-0.72	-0.30
lst_alcohol	584	1	2.54	1.40	1	6	0.65	-0.28
lst_harmful	584	1	1.90	1.43	1	6	1.66	1.84
lst_sleep	584	1	3.22	1.44	1	6	0.36	-0.64
lst_smoke	584	1	2.19	1.75	1	6	1.22	0.02
lst_smoke_r_r	584	1	2.25	1.82	1	6	1.07	-0.47
alcohol_r_r	584	1	2.96	1.78	1	6	0.29	-1.32

Note. Items are grouped by domain. For an explanation of item shorthand, see *CRP questionnaire* above.

Table C2 Standardized loadings of the PCA on 91 questionnaire items, 13-components solution

Item (shorthand)	TC1	TC5	TC7	TC9	TC13	TC4	TC3	TC2	TC6	TC8	TC12	TC11	TC10
cul_reading	0.78												
cul_buying	0.73												
cul_books_read	0.71												
cul_museums	0.61												
cul_museums_r_r	0.57											0.21	0.27
cul_workshops	0.48									0.2	0.21		
cul_theatre	0.45			0.24									
cul_documentaries	0.45									0.22			
cre_writing	0.44									0.27			
cul_documentaries_r	0.41												0.37
cul_news_r	0.39							0.25		-0.22			
mus_day		0.88											
mus_week		0.86											
mus_band		0.68											
mus_recitals		0.66											
mus_professional		0.61											
mus_amateur		0.53											
cre_classes		0.43								0.31			
cul_concerts		0.39		0.25									0.20
psup_encouragement			0.72										
psup_help_difficulties			0.72										
psup_care_homework			0.66										
psup_aware			0.65										
psup_ask_school			0.64										
psup_confidence			0.64										
psup_help_homework			0.58					-0.26					
fam_guests_homework				0.67									
fam_guests_play				0.60									
fam_night_out				0.58									
fam_meals_out				0.56								-0.21	
fam_guests_meals				0.54									
fam_guests_night				0.50									
fam_homework_out	0.23			0.47									
soc_tv				0.37						0.26			
cla_agreement					0.72								
cla_help_each_other					0.71								
cla_group					0.63								
cla_care					0.52								
cla_sharing					0.5			0.23					
cla_friends					0.49			0.21					
cla_get_along_r					0.49								0.32
cla_ideas					0.48								
cla_decisions					0.31								
cho_cleaning						0.78							

Item (shorthand)	TC1	TC5	TC7	TC9	TC13	TC4	TC3	TC2	TC6	TC8	TC12	TC11	TC10
cho_bed						0.70							
cho_room						0.67							
cho_table						0.65							
cho_grocery						0.49				0.20		-0.20	
cho_insist_r						0.47							0.21
cho_someone_else_r				-0.22		0.44		0.20					
cho_look_after						0.40				0.23			-0.20
cho_cooking						0.40		-0.25					
lst_smoke_r_r							0.83						
lst_smoke							0.83						
lst_harmful							0.78						
lst_alcohol							0.64						
alcohol_r_r							0.61			-0.24			
lst_sleep							0.3						-0.28
soc_company_r_r								0.64					
soc_company								0.55					
soc_involve_others								0.53					-0.21
soc_on_my_own_r								0.52					
soc_invited			0.24					0.48					-0.28
soc_no_difference_r				0.27				0.39					
fam_out_r_r				0.26				0.38		-0.24			
cre_share content								0.37					0.24
fam_guests_r_r				0.30				0.33					
spo_professional									0.82			-0.22	
spo_agonism									0.81				
spo_week									0.73			0.35	
spo_day									0.68			0.34	
cre_photos										0.63			
cre_share _content_r										0.56			
cre_film										0.46	0.20		
cre_exhibitions										0.46			
cre_decoupage										0.43			
cre_drawing	0.21									0.31			
char_funds											0.67		
char_goods											0.65		
char_volunteer											0.65		
char_community											0.48		
char_campaign					0.22						0.46		
lst_whatever_r												0.64	
lst_healthy												0.61	
lst_fast_food_r	0.24											0.54	
spo_amateur				0.3					-0.45			0.45	-0.21
lst_vegetables_r_r												0.41	0.28
cul_concerts_r_r		0.25		0.24				0.28					0.28
cre_acting_r_r													

Item (shorthand)	TC1	TC5	TC7	TC9	TC13	TC4	TC3	TC2	TC6	TC8	TC12	TC11	TC10
char_annoying_r											0.29		0.26
char_events									0.25		0.26		0.27

Note. See CRP questionnaire (above) for item shorthand meaning. Bold typeface denotes items retained in the final version of the questionnaire.

Table C3a Standardized loadings of the PCA performed on 69 questionnaire items, 12-components solution.

Item (shorthand)	Msc exp	Prt spp	Clt act	Hse Cho	Cls atm	Fml Opn	Sbs use	Spt	Scb	Cht	Diet	Crt act
mus_day	0.90											
mus_week	0.89											
mus_band	0.65											0.21
mus_recitals	0.64											
mus_professional	0.60											
mus_amateur	0.59											
psup_help_difficulties		0.72										
psup_encouragement		0.72										
psup_care_homework		0.66										
psup_aware		0.64										
psup_ask_school		0.64										
psup_confidence		0.62										
psup_help_homework		0.59							-0.25			
cul_reading			0.85									
cul_buying			0.80									
cul_books_read			0.77									
cul_museums			0.51							0.26		
cre_writing			0.46									0.25
cul_documentaries_r			0.32								0.23	
cho_cleaning				0.78								
cho_bed				0.73								
cho_room				0.68								
cho_table				0.66								
cho_insist_r				0.48								
cho_someone_else_r				0.48								
cho_cooking				0.38					-0.24			
cla_agreement					0.75							
cla_help_each_other					0.74							
cla_group					0.60							
cla_get_along_r					0.52						0.22	
cla_care					0.51	0.20						
cla_friends					0.47				0.27			
cla_ideas					0.47							
cla_decisions					0.32							
fam_guests_homework						0.72						
fam_guests_play						0.64			0.21			
fam_night_out						0.59	0.21					
fam_meals_out						0.57						
fam_guests_meals						0.55						
fam_guests_night						0.55						
fam_homework_out			0.27			0.51						
lst_smoke_r_r							0.87					
lst_smoke							0.85					
lst_harmful							0.79					
lst_alcohol							0.56				-0.21	
lst_sleep								0.82				

Item (shorthand)	Msc exp	Prt spp	Clt act	Hse Cho	Cls atm	Fml Opn	Sbs use	Spt	Scb	Cht	Diet	Crt act
spo_week								0.79				
spo_day								0.79				
spo_agonism								0.72				
spo_professional									0.64			
soc_company_r_r									0.64			
soc_involve_others									0.59			
soc_company		0.21							0.55			
soc_invited									0.52		0.20	
soc_on_my_own_r										0.69		
char_funds										0.65		
char_goods										0.63		
char_volunteer					0.20					0.48		
char_campaign										0.48		
char_community											0.71	
lst_whatever_r											0.64	
lst_healthy			0.21								0.61	
lst_fast_food_r											0.5	
lst_vegetables_r_r												0.69
cre_photos												0.69
cre_share _content_r										0.21		0.48
cre_film										0.21		0.48
cre_exhibitions										0.21		0.43
cre_decoupage							0.30					

Note. *Msc exp* = music experience; *Prt spp* = parental support; *Clt act* = cultural activities; *Hse Cho* = House chores; *Cls atm* = Class atmosphere; *Fml Opn* = Family openness; *Sbs use* = Substance use; *Spt* = Sports; *Scb* = Sociableness; *Cht* = Charity; *Crt act* = Creative activities

See Appendix 1 (CRP questionnaire) for item shorthand meaning.

Table C3b Component correlations and proportion of explained variance by component for the 12-components PCA solution on 69 items.

Component	1	2	3	4	5	6	7	8	9	10	11	12
1 Music experience												
2 Parent Support	-0,03											
3 Cultural activities	0,19	0,03										
4 House Chores	0,08	0,02	0,12									
5 Family Openness	-0,03	0,23	-0,04	0,03								
6 Class Atmosphere	-0,01	0,11	0,02	0,03	0,14							
7 Substance use	-0,02	-0,02	-0,13	-0,06	-0,03	0,12						
8 Sport	-0,04	0,12	-0,01	0,05	0,10	0,13	0,04					
9 Sociableness	-0,05	0,15	-0,08	-0,01	0,21	0,18	0,06	0,10				
10 Charity	0,12	0,04	0,19	0,14	0,04	0,16	-0,04	0,07	0,06			
11 Diet	0,09	0,09	0,10	0,08	0,04	-0,03	-0,16	0,07	-0,02	0,06		
12 Creative activities	0,14	-0,01	0,05	0,05	-0,01	0,11	0,03	-0,02	0,00	0,11	-0,01	
SS loadings	3,43	3,45	3,10	2,95	3,05	3,01	2,88	2,76	2,62	2,42	2,29	2,09
Proportion Var	0,05	0,05	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,03	0,03
Cumulative Var	0,05	0,10	0,14	0,19	0,23	0,28	0,32	0,36	0,39	0,43	0,46	0,49

Thank you

for your time and attention!