

# Cognitive Reserve Potential: Capturing cognitive resilience capability in adolescence

## Abstract

Cognitive reserve (CR) represents the adaptive response of the cognitive system responsible for preserving normal functioning in the face of brain damage. Experiential factors such as education, occupation, and leisure activities influence the development of CR. Theoretically, such factors build up from childhood and across adulthood. Thus, appropriate tools to define and measure CR as early as adolescence are essential to understand its developmental processes. To this aim, we introduce the construct of "Cognitive Reserve Potential" (CRP) and its corresponding index of experiential factors tailored to youth. We investigated prototypical youth exposures potentially associated with the lifelong development of CR (e.g., sport practice, musical experiences, cultural activities, relationships with peers and family).

Principal component analysis and confirmatory factor analysis identified and replicated the CRP factor structure on two independent samples of Italian students: N=585 (295 F) and N=351 (201 F), ages 11-20. CRP was associated mainly with family socio-cultural status (i.e., SES, Home Possessions and Books at Home).

Results confirmed the strength of the factorial model and warranted the proposal of the CRP-questionnaire as an innovative tool for understanding CR evolutionary dynamics.

**Keywords:** Cognitive Reserve, Adolescence, Self-report, Cognitive Reserve Potential, Experiential Factors, Lifelong Development

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 ageing, pathology, or insult” (Stern et al., 2020). In other words, a mechanism that could explain why people affected by a similar magnitude of brain damage show different degrees of impairment. The underlying theory is that more adaptable brain processes, supported by efficient, flexible, and high-capacity networks, can help individuals cope with structural brain damage or decline, thus minimizing their clinical manifestations. Hence, CR is a construct that focuses on the functional, rather than the structural, properties of the brain.

Due to the difficulty of identifying relevant brain networks and assessing individual differences in their expression, direct measures of CR are rarely available. Thus, CR is most frequently estimated by measuring the lifetime exposures or innate traits that support its development across the lifespan. To date, the predictive value of CR has been chiefly acknowledged with regards to neurological conditions in older adults (Bigler & Stern, 2015; Pettigrew & Soldan, 2019), and the main proxies identified by the literature are education, occupation, engagement in social and leisure activities, and early/premorbidity IQ (Nucci et al., 2012; Scarmeas & Stern, 2003; Stern et al., 2020; Valenzuela & Sachdev, 2006). Studies have shown that experience-based CR indicators (typically educational achievement, occupation, and engagement in cognitively stimulating activities) promote cognitive resilience over and above the effects of premorbidity cognitive ability (Baranyi et al., 2022; Dekhtyar et al., 2015). Moreover, assessing multiple indicators is more accurate and offers a more reliable representation of CR than single-indicator measures (Grotz et al., 2017; Jones et al., 2011; Kartschmit et al., 2019).

Currently, CR is increasingly called upon to explain the cognitive outcomes of brain dysfunction in children, who are not themselves immune to brain damage – of a traumatic origin or associated with various neurological pathologies. So far, efforts have focused

primarily on children and adolescents with Traumatic Brain Injury (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). However, CR is still a concept largely borrowed from adults' literature, with no theoretical adaptation to youth. Its measurement in young populations is extremely variable, limiting in turn its predictive power and the generalization of empirical results. For instance, in most Western societies, educational and occupational achievements have little variability before age 18, as many children are still engaged in mandatory schooling. For this reason, developmental studies tend to use either IQ or parental education to evaluate CR. The former is the most used proxy of CR in youth, often assessed through comprehensive batteries that include tests of verbal ability, reasoning, memory, and information processing speed (e.g., WASI - Hosseini et al., 2014). The latter is thought to hold a double informational valence: It reflects genetic endowment shared between parents and their offspring, and it correlates with environmental enrichment, learning experiences and quality of childcare. In other words, the single measure of parental education is the only proxy of experiential CR available for youth.

Here, we consider that IQ and parental education, however meaningful, cannot be expected to capture a breadth of life exposures comparable to that assessed in studies with adults. Children begin to build flexible cognitive processes as soon as they are engaged in any formal or informal learning activity, from playing in kindergarten to practising sports or social interactions. Such resources can remain available throughout their lives and come into play at a later age (Conte et al., 2022; Corley et al., 2022). Accordingly, we recognise this early form of capital as a crucial start-up or potential factor for CR: the very onset of *reserve*. In addition, juvenile exposures may contribute to individual differences in cognitive efficiency and resilience already at a young age. Of course, the amount of experience accumulated is by force small. Still, it can 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.

To further develop the definition and assessment of CR in youth, this work introduces a novel theoretical perspective, represented by the construct of Cognitive Reserve Potential (CRP). We define CRP as the adaptability of cognitive processes in adolescence that increases cognitive resilience in the short term and leads to CR in adulthood and older age, thus holding a double value. We qualify this construct as “CR *Potential*” for two main reasons: First, the simple need for youth-specific measures (vs. measures that may apply from 18 years onwards) calls for a different theoretical perspective on the onset of CR. Second, resource-accumulation processes may differ between a developing and a mature brain, even if the resources themselves play the same protective role and are preserved through the lifetime.

The main focus of the work presented here is on identifying youth-specific CRP proxies. Regarding the relationship to its experience-based indicators, CR has been qualified as a formative construct (Stern et al., 2020), conceived as being caused or defined by its measures (in contrast with reflective constructs, which hold the opposite status and are the cause or explanation for their measures). We believe the same relationship holds for CRP and its indicators. Formative indicators have a substantial theoretical role because they can influence the nature of the construct (Bollen & Lennox, 1991). Thus, developing age-appropriate definitions is necessary to ensure a coherent perspective on the CR construct across the life course (Grotz et al., 2017; Jones et al., 2011).

Here, we examine whether it is possible to detect, early in life, individual differences resulting from experiential and educational activities that may boost an individual's CR. To the best of our knowledge, ours is the first study to address this question. Pursuing such insights requires identifying and validating appropriate tools to assess CR in youth, also by conceptualizing it as a *Potential*. Hence, the primary purpose of the present work is to develop

an experience-based CRP evaluation for adolescents.

Our approach was partly inspired by the Cognitive Reserve Index questionnaire (CRIq; Nucci et al., 2012), an internationally adopted measure of CR for adults. The CRIq assesses education, occupation, and leisure activities and then, based on the type and duration of the activities, it produces three domain scores and one composite global score. The instrument main strength lies in combining multiple CR indicators instead of focusing on a single aspect. We aimed to reproduce these features in our Cognitive Reserve Potential Questionnaire (CRPq). Our goal was to capture as wide a range of experiences as possible. Therefore, we developed items assessing several aspects of school and classroom environment, peer relations, sports, music (i.e., singing or playing an instrument), family habits (e.g., chores, having guests, paying visits to other households), creative and cultural hobbies. We considered that, during adolescence, behaviours gradually transit from being influenced mainly by family and other environmental contingencies to being shaped by individual preferences and choices. Consequently, in the first study, we took care to investigate both aspects of adolescents' family and social context and characteristics of their personal experience. Next, in the second study, we tried to replicate the structure of our instrument in an independent sample, and we assessed a comprehensive range of cognitive abilities, executive functions and demographic factors to explore their relationship with our proposed socio-behavioural measure of CRP.

To conclude, the introduction of CRP and of the associated CRPq represents an attempt to elaborate on the developmental process of CR. In doing so, it provides scholars with a theoretically founded construct and clinicians with a comprehensive index that combines multiple facets.

In the methods sections of the two studies we report how we determined our sample size, all data exclusions and all manipulations.

# Study 1

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

## Methods

### Participants.

Participants in this study were 587 middle and high school students recruited during May and June 2018 in three schools in Northern Italy, in the provinces of Milano and Novara, and in one high school in the province of Massa-Carrara. Students belonged to a total of 42 classrooms with an average of 14 participants per class. Two participants who declared themselves to be younger than 8 and older than 22 years of age, respectively, were excluded from the analyses, leaving a final sample of 585 adolescents (295 females, mean age = 15.4 years, range = 11.3 – 20 years, SD = 2.3 years). This sample size was based on the resources (economic and human) available to data collection and it allows detecting, with 80% power, a correlation as small as  $r = .116$  in a two-tailed test and is generally regarded as “very good” for principal component and factor analysis (Comrey & Lee, 2013; see also MacCallum et al., 1999; Schreiber, 2021). Other data from the same participants were previously analysed to address distinct theoretical questions (masked).

### Measures.

Participants completed the first version of the CRP questionnaire together with measures of cognitive ability, cultural and socioeconomic status. These latter were described in full elsewhere (masked) and are briefly reported here.

*CRP 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 (a single domain encompassing diet, consumption of smoke/ alcohol and sleep habits). On 82 items, covering all sub-domains, participants were asked to express the frequency with which they experienced a certain attitude/behaviour on a 6-point scale scored from 1 to 6 (“never”, “hardly ever”, “sometimes”, “often”, “almost always”, “always”). The sports and music sections included 4 additional questions each, assessing more detailed information on these practices: Participants reported for how many years they practiced sport/music, whether they did so as amateurs or at a competitive/professional level, how many times per week they practiced and the average duration of a practice session. One additional question asked participants to report the number of books read in the previous year (excluding schoolbooks) on a 4-level scale: “less than 1 book”, “1-3 books”, “4-10 books”, “more than 10 books”. The list of original (91) CRP items is available as a supplement. 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. The question assessing the number of books read in a year was presented in the demographic section.

*Primary Mental Abilities – Verbal task* (Thurstone et al., 1957;  $\alpha = .92$ ). 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 study was adapted for digitalized administration to Italian students (masked). The score was the count of correct responses.

*Raven Standard Progressive Matrices* (Raven, 1941;  $\alpha = .91$ ). This task, used as an index of fluid intelligence, consisted of five series of 12 black-and-white pictorial matrices.



Each matrix was missing a piece and participants needed to identify it by choosing from a set of six options (series A – B) or eight options (series C to E). The score was the number of correct answers.

*Socioeconomic Status (SES; standardized  $\alpha = 0.85$ ).* 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 (ISCED - UNESCO Institute for Statistics, 2012): 1 = less than primary, 2 = primary, 3 = lower secondary, 4 = upper secondary, and 5 = tertiary. Occupational status for each parent was derived from participants' responses to open-ended questions. The descriptions they offered were first coded using the International Standard Classification of Occupation (ISCO-08) at the four-digit level and then mapped to the International Socio-Economic Index of occupational status (ISEI - Ganzeboom et al., 1992). ISEI values ranged from 1 to 89, with higher values indicating higher occupational status. A parallel analysis on the ISCED codes and ISEI scores of both parents suggested a single-component structure. Standardized loadings on the first component ranged from .81 to .86 and the component explained 70% 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 6-level pictorial scale to assess the number of books present in a household. These were 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, etc.). The home possession score was the sum of positive answers.

### **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.

Data collection was carried out at school. All measures were in digital format and were administered collectively to the members of each class. The researchers were present to introduce the study and to offer instructions, supervision, and support when required. Each student completed the questionnaire individually on a PC or tablet.

The study was conducted in compliance with the regulations issued by the Ethics Committee of (masked) and with the Helsinki Declaration (World Medical Association, 2013).

### **Statistical analyses.**

We explored the dimensions detected by the questionnaire and selected a subset of items (i.e., the analyses were performed on 91 questionnaire items). To control for age and gender variation, we partialled out age and gender from each item's score before further analyses (for a similar approach, see Nucci et al., 2012). We employed Parallel Analysis (Horn, 1965) and Principal Component Analysis (PCA) to explore how the items could be summarized by a limited number of dimensions. To obtain a subset of items which could maximize the parsimony and accuracy of the questionnaire, we excluded items with high cross-loadings or with no substantial loadings (i.e., no loading  $\geq 0.20$ ) through an iterative procedure, running new analyses after the removal of each item. The component scores estimated through the PCA

were used as individual subscale scores in further analyses. Consistent with the conceptualization of CR as a formative construct determined by the additive effects of multiple distinct indicators (Borsboom et al., 2003; Stern et al., 2020), we estimated global CRP as a composite score.

As a secondary aim, we explored the association between the CRP measure just obtained and age- and sex- independent scores on indexes of fluid and crystallized intelligence, and socio-cultural factors. Note that these relations will be explored more extensively in Study 2.

Analyses were performed in the R environment (R Core Team, 2022) using package *psych* (Revelle, 2020).

## Results

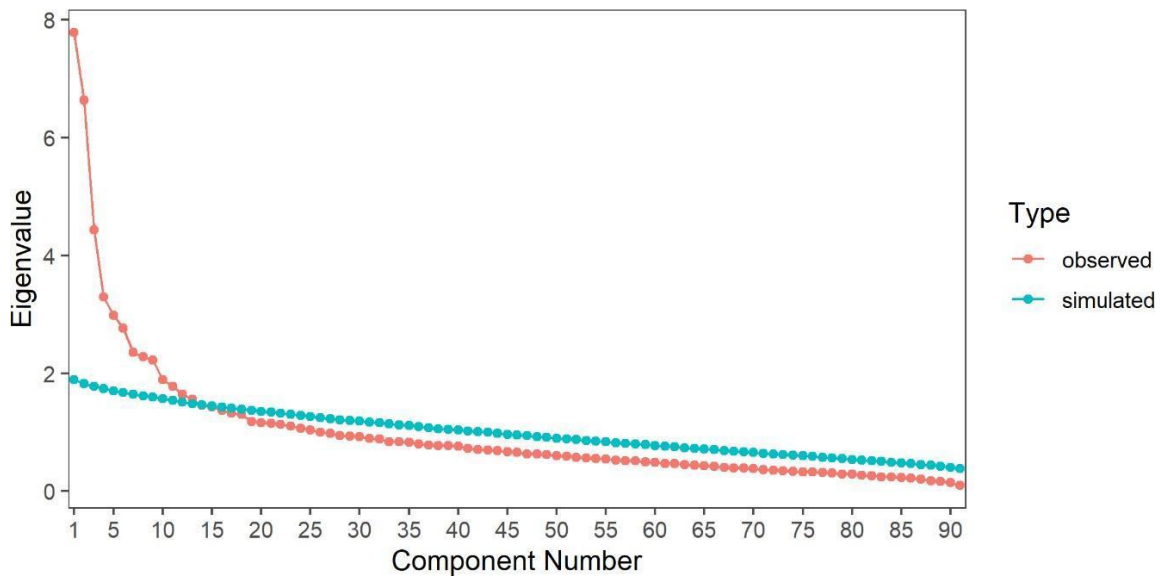
The list of questionnaire items and their descriptive statistics are reported in Supplementary Table S1. The initial parallel analysis and scree plot (Figure 1) on the full 91-items set (controlling for age and gender effects) both suggested the data was best represented by 13 components (standardized loadings in Supplementary Table S2a). Iterative item selection resulted in a final set of 69 items and a 12-components structure<sup>1</sup>. Upon examining the PCA component loadings (Supplementary Table S2b), we interpreted these components as (in order): music experience, parental support in studying, cultural activities, participation in house chores, family openness, classroom atmosphere, harmful behaviours, sports, sociableness, charity, diet, and creative activities. These components were a close match to the 11 dimensions we had initially planned to assess with the instrument. The most notable exception was the split

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<sup>1</sup> 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 13<sup>th</sup> component was not recovered.

of the *lifestyle* 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) and lack of sleep. The components showed small correlations (absolute *rs* below .21) and together accounted for 49% of the observed variance (Supplementary Table S3).

**Figure 1** Scree plot of the parallel analysis performed on 91 questionnaire items.



Eleven of the 12 CRP 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. Conversely, the 12<sup>th</sup> scale coded a potentially harmful behaviour, so its score was subtracted from the total of the 11 “positive” subscales to calculate global CRP.

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

Concerning the association between CRP and cognitive and sociocultural measures, this preliminary analysis showed that the global CRP score correlated positively and significantly with SES, Books at Home and Home Possessions (respectively  $r = .16$ ,  $r = .23$ ,  $r = .29$ ,  $ps < .001$ ). In contrast, it was not significantly associated with measures of cognitive ability. The Raven score correlated weakly with the score on the PMA and with sociocultural indicators (between  $r = .09$ ,  $p = .037$  and  $r = .28$ ,  $p < .001$ ). The PMA and sociocultural indicators had moderate to strong correlations (between  $r = .31$  and  $r = .59$ ,  $ps < .001$ ).

## Study 2

In study 2, our goals were i) to test the replicability 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 indeed frequently used CR indexes. Particularly, albeit variably measured, pre-morbid IQ 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 nor desirable (Nucci et al., 2012). In this study, we assessed two broad facets of intelligence, i.e., fluid and 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, occupation, and family cultural resources, with indicators mutated 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 to 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, which consequently requires several measures to be estimated reliably. For this very reason, we combined a set of digitalized tasks to tap into some of the main EF components suggested by Anderson (2002): attentional control, cognitive flexibility, information processing speed, and goal setting.

## **Methods**

### **Participants.**

An initial sample of 379 high school students took part in this study in May and June 2019. Students were recruited in three schools in Northern Italy, in the provinces of Lodi and Varese. A total of 25 classes were involved, with an average of 14 students per class. None of the participants had taken part in the research described in Study 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,  $SD = 1.04$ ). This sample size allows detecting, with 80% power, a correlation as small as  $r = .149$  in a two-tailed test and is regarded as sufficient for factor analysis (Comrey & Lee, 2013; see also MacCallum et al., 1999; Schreiber, 2021).

## **Measures.**

*CRP questionnaire.* The questionnaire used in this study consisted of the 12 scales (69 items) selected through the PCA in Study 1 (for a copy of the instrument see Authors, 2022

c). It included:

- 61 items scored on a 6-point frequency scale (“never”, “hardly ever”, “sometimes”, “often”, “almost always”, “always”),
- four items from the dedicated music experience section
- three items from the dedicated sports section (N.B. the fourth item, which read “*Check each year in which you practiced sport as an amateur*”, was not scored but was kept to preserve the symmetry between the music experience and the sports sections).
- the item “books read in a year”.

## ***Executive function assessment.***

All tasks were digitalised and run using Inquisit 5 software (*Inquisit 5*, 2016). Stimuli were presented on a computer monitor, from an approximate distance of 70 cm.

*Arrow flanker task* (adapted from Zelazo et al., 2013). Adopted to assesses inhibitory mechanisms and selective attention. The task required participants to respond to the direction of the central target arrow within an array by pressing a spatially compatible – left or right – key on the keyboard. The flanker arrows in the array acted as distractors. Stimuli were preceded by a visual cue and by a cue anticipating the location of the target (1000 ms each). Participants had 1750 ms to respond. The task consisted of three practice blocks with 4 trials each, followed by a test block with 40 trials. The proportion of congruent and incongruent trials and left/right facing targets was balanced throughout the task. The total duration was of approximately four minutes. Administration of the test block was contingent upon a 75% of correct responses in

the practice trials. The variable of interest was the “congruency cost”, computed as 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. The stimuli consisted in rows of 7 symbols: a set of two – the targets – appearing to the left of a set of five. For each row, participants were asked to look for a match amongst the 5 symbols on the right for either one of the two targets on the left and click on it. If none of the targets appeared in the 5-set, participants were instructed to click on the box marked “No”, at the right end of each row. A circle appeared to mark their choice. The rows of symbols appeared on the screen 10 at a time and participants were asked to mark an answer for each of them in order, starting from the top. Answers could not be changed once marked. The task had a time limit of 2 minutes. Once the participant had answered all the rows on the screen, if the 2 minutes had not elapsed, 10 new rows were shown. The test block was preceded by three examples showing the correct answers and by three practice rows providing feedback (i.e., participants were asked to “try again” until they marked all 3 correct answers). No feedback was given in the actual test. The variable of interest was the difference between the number of correct answers and the number of errors.

*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 on the basis either of the colour, the number, or the form of the figures appearing on them. After sorting each card, participants received feedback on the correctness of their choice. After 10 cards sorted correctly, the criterion changed without explicitly informing participants, requiring them 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 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). Participants were asked to identify either the global or local shape by pressing the corresponding keyboard key. The task consisted of three blocks: the first two, shown in random order, consisted of 10 practice trials and 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 and 40 test trials. Within this third “mixed” block the criterion was balanced and changed randomly in such a way as to present 50% of non-shift trials (which applied the 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, which was based on the “shift cost”: that is, 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 was a digitalized version of the original task. Completing the task required reproducing 12 configurations of increasing complexity, without exceeding the number of moves allowed. Each configuration could be attempted a maximum of three times. 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 crystallised intelligence.***

*Primary Mental Abilities – Verbal task* (Thurstone et al., 1957;  $\alpha = .71$ ). This was the

same synonym recognition task described in Study 1. It assessed receptive vocabulary knowledge, an indicator of crystallised intelligence.

*Raven abbreviated 9-item scale* (Bilker et al., 2012;  $\alpha = .54$ ). A short version of the Raven Standard Progressive Matrices (Raven, 1941), used as an index of fluid intelligence. The task presented a 9-item subset of the original matrices: items 11, 24, 28, 36, 43, 48, 49, 53 and 55. The score was the number of correct answers.

### ***Academic achievement.***

*Grades in Mathematics, Italian and English.* Participants self-reported their mid-term grades in Mathematics, Italian (grammar and literature) and English (grammar and literature). Grades were on a scale from 1 (lowest) to 10 (highest), with 6 conventionally representing the minimum passing grade.

### ***Socioeconomic and cultural factors.***

*Socioeconomic Status (SES).* ( $\alpha = 0.64$ ) The composite SES score was computed with the same procedure as in Study 1. The parallel analysis on the ISCED codes 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.

The *Books at home* (OECD, 2013; Sieben & Lechner, 2019) and *Home Possessions* (OECD, 2016) scales were the same as in Study 1.

### ***Procedure.***

The recruitment of participants followed the same procedure described for Study 1. All the instruments were digitalized and administered in a single session that lasted approximately

one hour. Members of the same class were tested simultaneously. Each participant completed the questionnaire and the tasks on a computer in their school's IT laboratory. 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, 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. The smallest sample size obtained,  $N = 42$ , allows detecting a correlation as small as  $r = .416$  in a two-tailed test, with 80% power.

### **Data exclusion criteria.**

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'"*). Six participants out of 351 answered incorrectly to two or more of these items and were excluded from the analyses.

Since the CRP questionnaire was the main measure of interest, participants who completed it carelessly were excluded from all analyses. Conversely, non-valid responses to one of the other tasks only warranted exclusion from analyses involving that specific 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 (on average, 1.25% of observed scores). On average, 1.25% of observed scores). In the arrow-flanker and the global-local tasks, mean response times below 200 ms were discarded as unreliable. In the arrow-flanker four participants had outlying scores and 31 were not presented with the task because they failed on 25% or more of the practice items, leaving  $N = 310$  for the analysis. Six participants were excluded from the global-local task because of mean reaction times shorter than 200 ms and four because of outlying scores, resulting in 153 valid ones. In the WCST, failure to complete at least one category (i.e., failure to sort at least 10 of the 128 cards correctly) was taken as an indicator of carelessness or misunderstanding of the task requirements. Two participants with no completed categories were excluded from analyses, together with 2 participants with outlying scores, leaving a sample of  $N = 341$ . A few outliers were also detected in other tasks: the Symbol Search (five outliers, valid  $N = 340$ ), the Tower of London (two outliers, valid  $N = 162$ ), and the PMA Verbal (three outliers, valid  $N = 155$ ). All 152 responders of the Raven Matrices were retained.

### **Statistical analyses.**

The first goal of this study was to validate the CRP questionnaire developed in Study 1. To do so, we tested the fit of the structural model identified in Study 1 on the new data with a Confirmatory Factor Analysis (CFA), and further compared it with a hierarchical model having CRP as a second order factor. Prior to the analysis, age and sex were partialled out of all scores by the same method adopted in Study 1.

The second goal of our study was to examine how CRP, as captured by our questionnaire, correlated with other factors of interest identified through CR literature. As in Study 1, CRP scales were identified based on the CFA model and factor scores were saved as individual scale scores. Consistent with conceptualizing CR as a formative construct determined by the additive effects of multiple distinct indicators (Borsboom et al., 2003; Stern et al., 2020), we estimated global CRP as a composite score. Such score was computed as the sum of the 11 “beneficial” scale scores, minus the *Harmful Behaviours* score. We examined the psychometric properties of the scale scores in the sample and the pattern of bivariate correlations between global CRP score, and age- and sex- independent scores on intelligence measures, executive function tasks, socioeconomic and cultural status scales. Given the number of comparisons, their significance level was adjusted using Benjamini and Hochberg’s (1995) method in the “corr.test” function in R. In the results, we present the adjusted significance levels.

The CFA model was estimated in the R environment (R Core Team, 2022) using the function “cfa” in package *lavaan* and the Maximum Likelihood (ML) estimator (Rosseel, 2012). We evaluated model fit based on the RMSEA, SRMR, CFI and TLI indices: RMSEA lower than .06, SRMR lower than .08, and CFI and TLI larger than .95 indicate good model fit (Hu & Bentler, 1999). Throughout the manuscript, we present standardised model estimates.

## Results

### **CRP model validation.**

The 12-component model of CRP factors developed in Study 1 was fit on data from 345 participants. Model fit was adequate: The SRMR (.067) and the RMSEA (.052) were both within the cut-off for acceptance. 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 lack of fit (Kenny, 2020). The fit of the hierarchical model was comparatively worse, as indicated by the larger values of AIC (72843.71 and 73274.15 for the 1<sup>st</sup> and 2<sup>nd</sup> order model, respectively) and BIC (73631.63 and 73850.68 for the 1<sup>st</sup> and 2<sup>nd</sup> order model, respectively), as well as by higher values of SRMR = .080, RMSEA = .053

Table 1 reports reliability estimates and descriptive statistics for all scales and for global CRP, along with bivariate associations between scales. This information refers exclusively to the sample involved in Study 2. Scale reliabilities ranged between  $\alpha = .60$  (for Creative activities) and  $\alpha = .85$  (for Music experience), with an average  $\alpha = .75$ .

Correlations among the scales were low to moderate, except for 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 harmful behaviours. On the other hand, the music experience, sports, and creative activities scales, together with participation in house chores, shared significant associations only with few other scales. The large majority of the correlations we observed were positive. Significant negative correlations were found only between harmful behaviours and the cultural activities and diet scales ( $r_s = -.18, p = .001$  and  $-.31, p < .001$ , respectively) and between cultural activities and sociableness ( $r = -.31, p < .001$ ), parental support ( $r = -.11, p = .040$ ), and family openness ( $r = -.15, p = .008$ ). Finally, the global CRP index ranged between  $-15.53$  and  $12.00$  ( $M = 0, SD = 4.78$ ).

**Table 1. Descriptive statics and bivariate correlations of CRP subscales and global score in Study 2**

	M (SD)	skew	kurtosis	alpha	n. items	1	2	3	4	5	6	7	8	9	10	11	
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 Harmful behaviours	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	

*Note:* Pearson bivariate correlations. Stars denote significance levels (\* $p \leq .05$ ; \*\* $p \leq .01$ ; \*\*\* $p \leq .001$ ); n items = number of items in the scale.

### **Associations of CRP with CR criteria.**

In Supplementary Table S4, 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).

Bivariate correlations between CRP and the other variables of interest are reported in Table 2. Correlations were weak to moderate: CRP was associated with SES, Home Possessions, Books at Home, and Italian grades: More home possessions, higher socioeconomic status, and more books corresponded to higher CRP ( $r = .22, p < .001$ ,  $r = .23, p = .001$ , and  $r = .14, p = .044$  respectively). CRP was also associated with better grades in Italian ( $r = .18, p = .006$ ).

The social, economic, and cultural measures correlated positively with each other (between  $r = .25$  and  $r = .35, ps < .001$ ), as did grades in Italian, Mathematics and English (between  $r = .23$  and  $r = .45, ps < .001$ ). The Symbol Search task had positive and significant correlations with several other cognitive tasks (i.e., Wisconsin CST, Tower of London and Raven short form). A higher score in the abbreviated Raven matrices was significantly associated also with a higher score in the Wisconsin CST, in the Tower of London task, and with better English grades. Notably, all scores were independent of both age and sex, and there were no significant associations between scores in cognitive/executive function tasks and CRP or indicators of social, economic, and cultural status.



**Table 2. Bivariate correlations among CRP and measures of cognitive and executive functions, socioeconomic and cultural status, and academic achievement. Corrected by age and gender.**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 CRP	<i>345</i>	310	340	341	153	162	155	152	345	345	345	345	345	345
2 Arrow Flanker	-.01	<i>310</i>	306	306	138	148	140	141	310	310	310	310	310	310
3 Symbol Search	.04	-.04	<i>340</i>	336	151	161	153	149	340	340	340	340	340	340
4 Wisconsin CST	.01	-.06	.18**	<i>341</i>	151	159	154	151	341	341	341	341	341	341
5 Global - Local	-.06	-.24*	.04	.02	<i>153</i>	46	47	41	153	153	153	153	153	153
6 Tower of London	.00	.03	.20*	.12	-.10	<i>162</i>	44	42	162	162	162	162	162	162
7 PMA - Verbal	-.01	-.05	.17	.11	-.07	-.09	<i>155</i>	59	155	155	155	155	155	155
8 Raven short	.07	-.01	.28**	.22*	-.14	.53**	.12	<i>152</i>	152	152	152	152	152	152
9 SES	.22***	-.09	.02	.00	.04	.07	.00	-.09	<i>345</i>	345	345	345	345	345
10 Home Possessions	.23***	-.05	.04	.01	-.05	-.06	-.03	.13	.25***	<i>345</i>	345	345	345	345
11 Books at Home	.14*	-.04	.04	.07	.03	.10	.13	.10	.35***	.35***	<i>345</i>	345	345	345
12 Grade Italian	.18**	-.05	.08	.04	.06	.05	.10	.11	.10	.12*	.16*	<i>345</i>	345	345
13 Grade Math	.05	-.08	.08	.07	.13	.13	.08	.01	-.05	.04	.00	.45***	<i>345</i>	345
14 Grade English	.11	-.08	.08	.10+	-.02	.18	.17	.24*	.04	.07	.11	.40***	.23***	<i>345</i>

*Note.* Age- and gender- independent scores. Pearson bivariate correlations. Stars denote *fdr*-adjusted significance levels (\**p* ≤.05; \*\**p* ≤.01; \*\*\**p* ≤.001). Values on the diagonal (in italic) show sample size for each measure, values above the diagonal show sample size for each correlation.

## General Discussion

### **Socio-Behavioural Indicators of CRP in Adolescence.**

The main aim of this work was to truly extend the concept of CR to youth on both the theoretical and the methodological level. In order to do so, we developed the construct of CRP, focusing on the experiences that promote the flexibility and adaptability of cognitive processes in youth. At the same time, we developed an instrument to measure the socio-behavioural factors associated with CRP in adolescence (Authors, 2022). To our knowledge, socio-behavioural proxies of CR have all been modelled on adults and have limited use on youth. To account for the role of personal experiences in CR development, we created a questionnaire collecting information on a wide variety of situations common in Italian adolescents' lives. Using PCA in Study 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 harmful behaviours. The results from the CFA in Study 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 indicators mentioned above, some are similar to those used on adult populations (e.g., sports, music experience, cultural and creative activities, and charity). Other indicators are age-adjusted adaptations of dimensions commonly assessed in adults: The CRI-q measures domestic chores such as cooking, cleaning, grocery shopping, whereas the CRP measures participation in house chores with items such as “*keeping my room in order*”, “*making my bed*”, and “*setting the table*”. Finally, others still 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 closely matched the areas we initially proposed to investigate: The only notable difference was the split of the Lifestyle area into Diet and Harmful behaviours. We hypothesized that eating habits, smoke, alcohol, and drug consumption would all be influenced by a general awareness of and care for 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) is only weakly related to food choices ( $r = -.31$ ,  $p < .001$ ).

The good internal consistency and the 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, despite sharing an aspect of content or material creation, creative activities included a diverse array of endeavours, ranging from photography to decoupage. The scales that had a broader range and greater magnitude (between  $r = -.16$  and  $r = .76$ ) of correlations were those concerning relationships with others (i.e., parental support in studying, family openness, classroom atmosphere and sociableness), as attitudes and behaviours tended to be stable across social circles. Participants reporting availability and encouragement from their parents were also more likely to indicate that they enjoyed spending time with their peers and lived positive interactions in the classroom. One possible reason why these areas of experience, compared to others, appeared to have more numerous and stronger associations is that they capture habits applicable across occasions and situations, with peers in and out of school, and with family members. On the other hand, scales such as music experience, sports or creative activities investigate behaviours that are more likely to be mutually exclusive and coherently showed weak to moderate correlations (below  $r = .38$ ). Given the time and energy constraints that we all experience in our daily lives, 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, CRP is 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 (Borsboom et al., 2003; Stern et al., 2020). As such, high inter-scale correlations were not expected, nor especially desired. Instead, it was important to include several different dimensions so as to capture all the different pathways through which children may develop their CRP.

### **Associations of CRP with Measures of Intelligence, Executive Functioning, Academic Achievement, and Socioeconomic and Cultural Status.**

The second goal for Study 2, motivated by the promising results of Study 1, was to examine the associations between our proposed CRP measure and existing indicators of CR in youth, namely socioeconomic and cultural status (e.g., parental educational and occupational achievement, cultural resources) and intelligence. We additionally included in the analyses measures of academic achievement and executive functions. The former were intended as more ecological indicators of cognitive performance, albeit less accurate. The latter capture aspects of cognition often associated with the flexibility, capacity and adaptability of cognitive networks that sit at the heart of CR theory (e.g., Siedlecki et al., 2009).

CRP was significantly and positively associated with the SES, Home Possessions, and Books at Home scales in both studies. Given the theoretical common ground among these factors, such a result was expected. We have already mentioned how parental education and occupation (here synthesized by SES) can indirectly shape children's environment and experiences during development (Baranyi et al., 2022; Kesler et al., 2010). The presence of educational and cultural items in the household, including books, further enriches the

environmental characterization, and CRP complements this information by directly assessing youth daily activities and attitudes. The modest magnitude of the correlations also supports our initial hypothesis that, although the home and family environment still strongly influence personal experiences, adolescence represents a turning point in the development of personal autonomy.

CRP was found to correlate positively with Italian, but not Math and English grades. Measures of academic performance, such as school grades, result from complex interactions among several factors: social and environmental resources, student motivation, and cognitive abilities, to name just a few. Still, the fact that CRP correlated only with some of the school grades suggests that personal experiences have a differential impact on the specific cognitive skills required by each subject. Namely, the performance in Italian, the native language of most students, arguably relying more on verbal (crystallised) abilities, was experience-sensitive. On the other hand, the performance in a second language and in math, arguably relying more on factors such as abstract reasoning and working memory, had a weaker association with CRP.

Our analyses did not detect any association between CRP and intelligence or executive function tasks, contrary to what would be expected based on adult CR studies (Mitchell et al., 2012; Roldán-Tapia et al., 2012). We hypothesise that this result is due to a structural difference between the CRP-q and adult CR indicators such as the CRI-q. Our questionnaire refers to current behaviours and attitudes (i.e., typical around the time of the assessment). In contrast, instruments tailored to adults consider behaviours across the entire life-course, spanning years or decades before the time of evaluation. Personal experiences may bear a negligible relationship to cognitive skills measured contextually, instead exercising their influence over a more extended period. This is even more critical when considering the complex interplay between personal and familial determinants of experiences in adolescence. The development of autonomy is crucial for adolescents and determines a substantive inter-individual variability

in the choice and frequency of activities. At the same time, adolescents are minors and most live with their families; therefore, their activities are only partly self-determined (e.g., their house and neighbourhood are chosen by their guardians and they need an adult's consent to enrol in extracurricular sports or artistic endeavours).

Finally, the lack of other expected associations, such as between Books at Home and scores on the PMA-Verbal test, could suggest that sample or methodological issues at least partly confound the results of Study 2, as we will discuss in the following section.

### **Limitations.**

This work raised a few key issues that should be addressed when planning future CRP research. The first issue concerns the time frame of data collection. The cumulative nature of CR and CRP suggests that life exposures at a given age can impact the adaptability of cognitive processes later in life. The choice of assessing *current* experiences through the CRPq, while aiming to reflect the dynamic experiential background of adolescents, likely requires a longitudinal design to be fully appreciated and adequately evaluated.

The second issue concerns sample features. While far from small, Study 2 sample was a convenience sample recruited in a setting – that of public high schools in suburban areas of Lombardy – where social and demographic characteristics of students and families tend to be relatively uniform. This might have resulted, for instance, in a somewhat low within-sample variability of PMA scores, which could partly explain the absence of expected correlations with other socioeconomic and cognitive measures (A Levene test revealed a significantly smaller variability in the PMA in the present study,  $SD = 4.74$ , compared to the sample of Study 1,  $SD = 7.99$ , Levene's  $F = 56.013$ ,  $p < .001$ ). Furthermore, the planned missing data design sensibly restricted the sample size in some analyses. An adequate study of these phenomena will require different sampling choices based on the small-to-moderate correlations between CRP and

cognitive tasks. Future work should ensure greater diversity within the sample and a larger baseline sample size.

Finally, a critical difference between our study and the bulk of CR literature was 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. Despite offering clear advantages (i.e., time efficiency, standard task presentation) it still suffers from the scarcity of validated instruments and population-based norms. The lack of normative data made it difficult to evaluate the reliability and accuracy of our measures. One concern is that grouped administration could have proved particularly distracting for some participants. Researchers were present during each testing phase and collaborated with teachers to ensure that the environment was quiet and conducive to focused effort (e.g., by positioning participants sufficiently far from each other). Still, we could not completely rule out a methodological confounding of the associations between intelligence and EF scores and other factors. Further research is needed to fully gauge the impact of the different methods and to provide test validation and normative data.

## **General conclusion**

We introduced the construct of CRP, a theoretical adaptation of CR specific to youth, in order to represent those experience-dependent cognitive resources which develop during adolescence: A Potential that, during the lifetime, blossoms into the well-studied CR of adults. Furthermore, we had the ambitious goal of detecting a single CRP indicator. 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 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.

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The authors declare to have no conflicting interests.

The data that support the findings of this study, the CRP questionnaire, the adapted PMA

Verbal and the Inquisit scripts for EF tasks are openly available in OSF at

[https://osf.io/vberj/?view\\_only=e69535a0e20c4e408e04f07f5707e00b](https://osf.io/vberj/?view_only=e69535a0e20c4e408e04f07f5707e00b)

The analysis code is currently available from the first author and will be made publicly available on the OSF repository upon acceptance. The analyses were not pre-registered.



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

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