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

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1. Introduction

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, Conway, Ketron, & Bornstein, 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, Wilhelm, & Schroeders, 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 (WJ-IV; Woodcock, R. W., Schrank, F. A., Mather, N., & McGrew, 2014) (for tests and batteries assessing language competences, see Flanagan, Ortiz, & Alfonso, 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 (as examples, see Oliveira, Nitrini, Yassuda, & Brucki, 2014; Wittorf, Wiedemann, & Klingberg, 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, Mapelli, & Mondini, 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).

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 (van der Maas et al., 2006), positive correlations between cognitive measures are ascribed to mutual causal interactions among them and with the environment (van der Maas, Kan, Marsman, & Stevenson, 2017). An example of such interactions is described also in the investment theory (Cattell, 1987; 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 (e.g., 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, Borsboom, & Fried, 2018; Epskamp, Rhemtulla, & Borsboom, 2017). 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, Waldorp, Mõttus, & Borsboom, 2018). Such undirected network models allow to examine the relationships among several cognitive abilities and relevant environmental conditions simultaneously (e.g., Kan, van der Maas, & Levine, 2019), without needing to specify the direction of the effects, which is undetermined in cross-sectional studies (Epskamp et al., 2017; MacCallum, Wegener, Uchino, & Fabrigar, 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.

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, Duffett-Leger, Levac, Watson, & Young-Morris, 2013). SES is a robust predictor of individual differences in language development (Hackman & Farah, 2009; Thomas, Forrester, & Ronald, 2013) and research has linked economic, social and cultural assets of the family to students' educational outcomes, including verbal abilities (Bukodi & Goldthorpe, 2013; Dahl, Lochner, & Gordon Dahl, 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, Howell, & Crain, 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, Brooks-Gunn, & Kohen, 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, 2019a; 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, Evans, & Kelley, 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 (e.g. OECD, 2016; Schulz et al. 2016; Mullis et al. 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 (Sikora et al., 2019; Evans et al. 2016). 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 (van der Maas, 2016; Rinaldi & Karmiloff-smith, 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 (see for example Tucker-Drob & Bates, 2016).

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, Sartori, & Brivio, 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, Lehrl, Galster, & Erzigkeit, 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 (see for example 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.

1. 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, Starr, Whalley, & Fox, 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 & Thurstone, 1949; Thurstone, Thurstone, & Formaggio, 1957) 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.

2. Methods

3.1 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 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.

3.3 Measures

3.3.1 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 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. Supplementary Table 2 lists frequency, familiarity and answer options for all items, including also the stimuli excluded from the final version of the task.

Raven SPM (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.

3.3.2 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, De Graaf, & Treiman, 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, p. 38; Sieben & Lechner, 2019a) 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.

3.3.3 Analyses 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 (Albert 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 (Alberto Maydeu-Olivares, 2015), for which similar criteria to those used in Structural Equation Models apply (Hu & Bentler, 1999; Alberto 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, Waldorp, 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, Hastie, & Tibshirani, 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, Wang, & Witten, 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[1]. The lasso regularization requires to select a parameter that regulates the amount of penalization. The regularization parameter was selected through the Extended Bayesian Information

[1] 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)

Criterion (EBIC; Chen & Chen, 2008; Foygel & Drton, 2010), as implemented in the R packages *bootnet* (Epskamp, Borsboom, et al., 2018) and *qgraph* (Epskamp, Costantini, et al., 2018; Epskamp, Schmittmann, & Borsboom, 2012), using the default value of .50 for the EBIC hyperparameter. Furthermore, we employed the threshold parameter proposed by Jankova 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).

4. Results

4.1 Psychometric properties of PMA

Supplementary Table S1 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 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 ($BF = 1.62*10\text{^}41$). 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 Supplementary Table S1. 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 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 1. *IRT Model comparisons*

Model	N. parameters	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

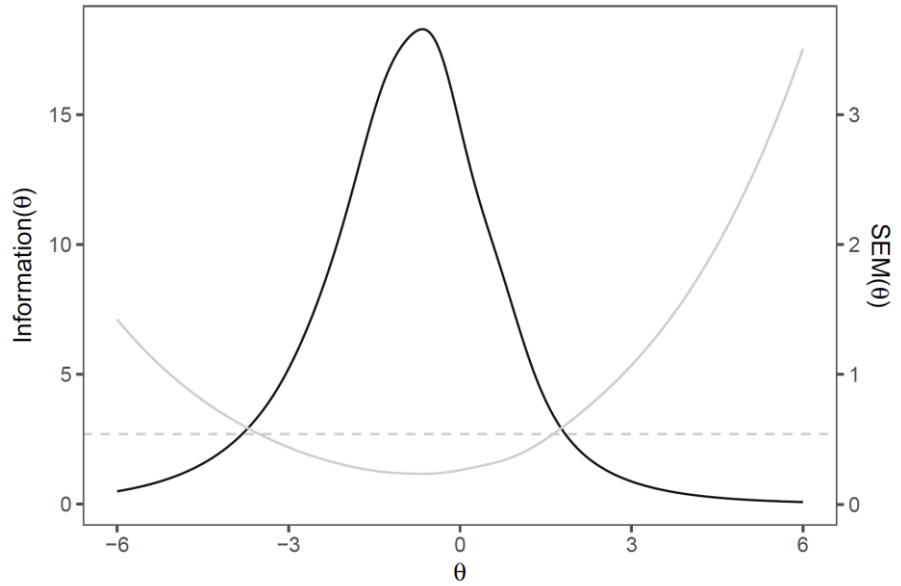

Figure 1. Test information function (black line) and Standard Error of Measurement (grey line) of the PMA-Verbal task. The dashed horizontal line marks a SEM value of .54.

4.2 Network of socio-economic and cultural factors and Cognitive Abilities

Table 2 reports descriptive statistics and correlations for each of the variables considered in the network.

Table 2. *Descriptive statistics and correlations*

	Descriptive Statistics					Correlations						
	Mean	*SD*	*skewness*	*kurtosis*	Predictability	1	2	3	4	5	6	7
1. Gender	0.50	0.50	-	-	0.14							
2. Age	187.23	27.52	-0.17	-1.02	0.34	-.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.
** p < .05, ** p < .01, *** p < .001*

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 2, whereas exact values of each edge together with their bootstrapped confidence intervals are reported in Table 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 2 (for exact values see Table 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.

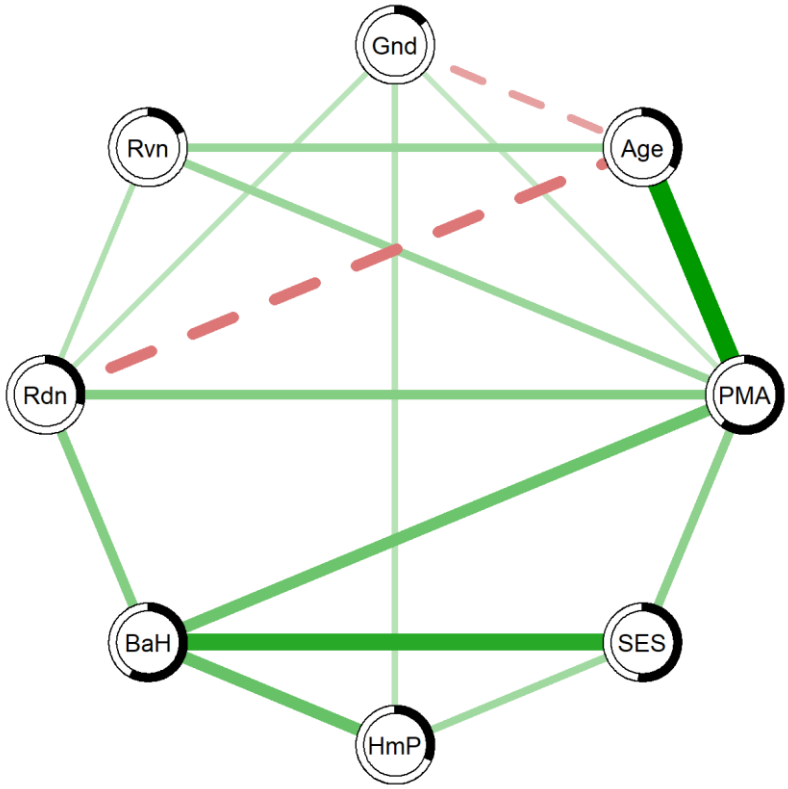

Figure 2. Network including Age, Gender (Gnd, f = 1 and m = 0), the adapted Primary Mental Abilities Verbal task (PMA), Socio-Economic Status (SES), Home Posessions (HmP), Books at Home (BaH), Reading Habits (Rdn), and Raven Matrices (Rvn).
The pie chart around each node represents its predictability. Dashed edges represent negative relationships.

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

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 [0; .26]
PMA--Rvn	.18 [0; .26]
SES--HmP	.17 [0; .25]
Gnd-Age	-.17 [-.24; 0]
Rdn--Rvn	.14 0; .23]
Gnd—HmP	.13 [0; .20]
Gnd--Rdn	.12 [0; .20]
Gnd—PMA	.11 [0; .18]

5. Discussion

5.1 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 behavior, 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.

5.2 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 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 (e.g. Lipina et al., 2013; Rindermann, Michou, & Thompson, 2011; Sieben & Lechner, 2019b; van Bergen, van Zuijen, Bishop, & de Jong, 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 (see for example Evans, Kelley, Sikora, & Treiman, 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, Krajnc, Klanjšek, Musil, & Kirbis, 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., 2010a). 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, Kelley, Sikora, & Treiman, 2010b). 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.

5.3 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 coul 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. Finally, 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.

6. General conclusions

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.

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