

1 Article

2 Mind-Personality Relations from Childhood to Early 3 Adulthood

4 Andreas Demetriou¹, George Spanoudis², Mislav Stjepan Žebec³,

5 Maria Andreou², Hudson Golino⁴, and Smaragda Kazi⁵

6 ¹. Department of Psychology, University of Nicosia, 1700 Nicosia, Cyprus

7 ². Department of Psychology, University of Cyprus, 1678 Nicosia, Cyprus; spanoud@ucy.ac.cy
8 (G.S.); maria.polydorou@cytanet.com.cy (M.P.)

9 ³. Department of Psychology, Croatian Studies University of Zagreb, 10 000 Zagreb, Croatia;
10 mzebec@hrstud.hr

11 ⁴. Department of Psychology, University of Virginia, 22903 Charlottesville, USA;
12 hfgolino@gmail.com

13 ⁵. Department of Psychology, Panteion University of Social Sciences, 176 71 Athens, Greece;
14 smakazi@otenet.gr

15 * Correspondence: ademetriou@ucy.ac.cy; Tel.: +00357 99697199

16

17 **Abstract:** We present three studies which investigated the relations between cognition and
18 personality from 7 to 20 years of age. All three studies showed that general cognitive ability and the
19 general factor of personality are significantly related throughout this age span. This relation was
20 expressed in several ways across studies. The first investigated developmental relations between
21 three reasoning domains (inductive, deductive, and scientific) and Eysenck's four personality
22 dimensions in a longitudinal-sequential design where 260 participants received the cognitive tests
23 three and the personality test two times, covering the span from 9-16 years. It was found that initial
24 social likeability significantly shapes developmental momentum in cognition and vice-versa,
25 especially in the 9 to 11 years period. The second study involved 438 participants from 7 to 17 years,
26 tested twice on attention control, working memory, reasoning in different domains, and once by a
27 Big Five Factors inventory. Extending the findings of the first, this study showed that progression
28 in reasoning is affected negatively by conscientiousness and positively by openness, on top of
29 attention control and working memory influences. The third study tested the relations between
30 reasoning in several domains, the ability to evaluate one's own cognitive performance, self-
31 representation about the reasoning, the Big Five, and several aspects of emotional intelligence, from
32 9 to 20 years of age (N=247). Network, Hierarchical Network, and Structural Equation modeling
33 showed that cognition and personality are mediated by the ability of self-knowing. Emotional
34 intelligence was not an autonomous dimension. All dimensions but emotional intelligence
35 influenced academic performance. A developmental model for mind-personality relations is
36 proposed.

37 **Keywords:** personality; intelligence; development; cognition;

38

39 1. Introduction

40 Mental processes and motivational and personality dispositions interact to guide understanding
41 and action in the world. Wechsler argued that "general intelligence cannot be equated with
42 intellectual ability but must be regarded as a manifestation of the personality as a whole." [1], (p. 83).
43 Allport [2], (p. 48) suggested that personality is "the dynamic organization within the individual of
44 those psychophysical systems that determine his unique adjustment to his environment". In Cattell's

45 [3] model intelligence and personality occupy equal standing. However, there is no generally
46 accepted model specifying when and how cognitive and personality processes interact. Recognizing
47 this lack, Jensen [4] concluded “The g factor”, his magnum opus on general intelligence, urging
48 researchers to study the intelligence-personality nexus.

49 The studies presented here explore this nexus, tracing its changes in development. It is well
50 known that, on the one hand, individuals at different ages understand the world differently despite
51 possible similarities in personality [5]; on the other hand, early differences in personality may channel
52 individuals to relate differently with the world, despite their intellectual similarities, eventually
53 differentiating their developmental opportunities [6,7]. For instance, reflective individuals may
54 control motivational and personality dispositions, achieving better adaptation in their environment
55 than less reflective individuals. No satisfactory model exists for these interactions. This paper
56 presents three studies designed to highlight the relations between cognition and personality from
57 several points of view. Specifically, all three studies examined (i) if cognition and personality are
58 systematically related; (ii) how different component process in each interact with components in the
59 the other; (iii) if there is a central mediator underlying these interactions; and (iv) disentangle their
60 relative influence on real life outcomes such as academic achievement. Below we review literature
61 related to the organization of intelligence and personality, their development, and their possible
62 interactions in development. This introduction concludes with predictions suggested by this
63 research.

64 65 1.1. The Organization of Cognition and Personality: Commonalities and Differences. 66

67 In recent years, there has been significant progress in the study of the organization of intelligence
68 and personality and their possible common ground (e.g., [8-10]). There is consensus that both are
69 hierarchically organized. Specifically, intelligence is a three-level hierarchical structure involving
70 three types of systems: (i) several broad domains of ability, such as spatial, verbal, and quantitative
71 reasoning; (ii) domain-general systems of inferential and representational processes, such as *fluid*
72 *intelligence* (Gf; basically inductive reasoning allowing processing of similarities and relations at
73 increasing levels of abstraction) and *crystallized intelligence* (Gc; knowledge and skill systems
74 crystallizing learning and experience that may be activated for understanding and problem solving;
75 (ii) a general factor (g) mainly associated with processing efficiency, attention control, mental
76 flexibility, and working memory [4,11-13]. Cognizance was recently added as a major background
77 process of g. This includes a suit of processes including self-monitoring of mental and behavioral
78 processes, representation and awareness of them, reflection on and intentional regulation of them,
79 and metarepresentation which generates new mental and behavioral constructs out of the
80 modification and integration of available constructs [5, 14-16].

81 *Personality.* In personality, a structurally equivalent hierarchical model is gaining popularity.
82 This model specifies several dimensions standing for specific dispositions to relate with the world.
83 According to the Big Five Factors model, which dominates the field, these dimensions are: *extraversion*
84 (E, enjoying being with others and actively seeking social company and activity); *agreeableness* (A,
85 orientation to others, trusting them and be warm with and make good to them); *conscientiousness* (C,
86 goal-minded, focused, careful, organized, determined, and planful; *neuroticism* (N, individuals high
87 in neuroticism are disturbed by variations in the environment so that they are nervous, anxious, and
88 moody); *openness to experience/intellect* (O, being curious, inventive, original, and imaginative with
89 wide interests and trying new experiences). The Big Five Model integrated constructs from earlier
90 models of personality. It shares two of the Big Five with Eysenck's [17] theory (E and N) and overlaps
91 with the third, *Psychoticism* (P), which combines traits of A and C [18-20]. It also integrated openness
92 from Cattell's [3] model, standing for the projection of mental ability in personality.

93 Evidence shows that three of the Big Five Factors relate to one and the rest to another second-
94 order factor: C, N (emotional stability), and A relate to the general trait of stability, the α -factor,
95 underlying efficiency in organizing one's own life, dealing with pressure, and making oneself
96 acceptable; the other, the beta factor (β -factor), relates with O and E, and stands for plasticity in one's

97 relation with the world. In turn, these two factors relate to a third-order general factor, the General
98 Factor of Personality (GFP). Broadly speaking, these factors appear related to the higher-order factors
99 in the hierarchical model of intelligence outlined above. Stability associates with crystallized
100 intelligence, including dispositions and skills underlying interactions with the social world; plasticity
101 expresses fluid intelligence in personality. "The GFP is analogous to g and predicts social efficiency
102 in the way g predicts cognitive efficiency" [21], (p. 564). GFP, like g , relates to actual life indicators,
103 such as performance at school and work (e.g., [22]).

104 Despite their possible similarities in overall structure, there is a large uncharted territory
105 between intelligence and personality. For instance, we do not yet know if there is a super- G , over g
106 and the GFP, capturing processes and functions integrating mental and personality functioning. This
107 would stand for the whole person, g_P , and it would represent an individual's mental and behavioural
108 uniqueness. For instance, one might claim that g , general mental power, is projected into one's self-
109 concept [23] as general self-efficacy [24], confidence in self-evaluations of performance across
110 domains [25], and even Freud's Ego and ego strength [26]. That is, g , standing for outcomes of the
111 individual's cognitive activity as measured by the researcher, and the GFP, standing for one's own
112 evaluation and representation of these outcomes share a common ground, success in problem solving
113 and interactions and evaluations of it—carried out by oneself and others and mutually broadcasted.

114 It is interesting that the general factor is disputed in both fields. In intelligence, scholars argue
115 that g does not really exist; in their view, g is a statistical artefact reflecting the interaction between
116 processes activated according to the requirements of the current task rather than any specific mental
117 process [27,28]. Along the same line, in personality, scholars claim that GFP may be a technical
118 artefact, additionally reflecting a generally present likeability tendency reflected in all Big Five
119 Factors [29]. Currently, the evidence about the commonalities between intelligence and personality
120 is inconsistent. On the one hand, research on the genetic (e.g., [30]) and the brain basis [31-32] of
121 intelligence and personality suggests that specific genetic profiles channel brain formation and
122 functioning imposing common constraints on mental and personality functioning. For instance,
123 specific genes channel the operation of neurotransmitters, such as dopamine and serotonin, which
124 relate to psychological characteristics common to both intelligence and personality, such as novelty
125 seeking and emotional reaction to stimulation [33-34]. On the other hand, however, there is evidence
126 that the genetic correlation between the general factors of intelligence and personality is 0 [35].
127 Obviously, systematically establishing or falsifying the possible relation between g and the GFP is
128 important for several lines of ongoing research. All three studies to presented here shed light on this
129 question.

130 Specifically, we will examine if there are common background processes operating in both
131 personality and intelligence. We will focus on two distinct but related processes: executive control
132 and cognizance. Executive control, the ability to focus on stimuli, plan action, and flexibly change
133 focus as needed, is a central component of Gf in current models of intelligence. Cognizance is an
134 active translation agent that transforms executive control experiences into regulation schemes that
135 may be used in managing inferential processes and vice-versa [15-16]. In personality, these
136 mechanisms may be involved in two different dimensions. As mechanisms of regulation and
137 planning, they may underlie the self-discipline and stability involved in C ; as mechanisms of
138 flexibility, they may be instrumental for sustaining plasticity in dealing with others (E) or with
139 novelty (O) [7]. We know of no research that explored these questions. It is noted, however, that all
140 personality theories, including the Big Five Factor model, are largely based on self-rating inventories.
141 Therefore, personality research and theory take for granted that there is a self-monitoring and self-
142 recording agent that is minimally accurate to describe dispositional and behavioural actualities:
143 responses to personality inventories are generated by this agent. Indeed, there is strong evidence that
144 the GFP is highly self-representational, reflecting a person's self-concept and self-worth rather than
145 actual cognitive ability: the relation between GFP and self-esteem is very high (67% of the variance)
146 [38]. Also, self-represented cognitive g accounts for much more of the variance of all Big Five
147 (between 18-25%) but N (1%) than Gf (between 1-3%) [39]. We assume that these self-concepts are
148 products of the operation of cognizance, which varies in accuracy and scope with development [5,

149 15, 38, 39]. Therefore, it is important to specify how cognizance relates to the various intelligence and
150 personality factors and mediates between them at successive developmental phases.

151

152 *1.2. Development of Cognition and Personality*

153 *Cognitive development.* There is general agreement that intelligence develops over a series of
154 levels from birth to early adulthood. Macroscopically, theories of cognitive development agree that
155 major transitions occur around the age of 2, 7, and 11 years, when thought changes in abstraction,
156 cohesion, and reasoning power. These changes were associated with increasing processing and
157 representational efficiency as indicated by functions such as processing speed, attention control, and
158 working memory [40-42]. Integrating over these theories and a long series of empirical studies, we
159 postulated that cognitive development occurs in four major developmental cycles, with two phases
160 in each. New representations emerge in the first phase of each cycle and their integration dominates
161 in the second. Transitions across cycles is driven by cognizance, i.e., increasing self-awareness of
162 mental representations and processes, reflection, metarepresentation engendering new
163 representations, and ensuing self-regulation [5,16].

164 In succession, the four cycles operate with episodic representations from birth to 2 years, realistic
165 mental representations from 2 to 6 years, generic rules organizing representations into
166 conceptual/action systems from 6 to 11 years, and overarching principles integrating rules into
167 systems where truth and multiple relations can be evaluated from 11 to 18 years. Changes within
168 cycles occur at about their middle, at 4, 8, and 14 years, when representations become explicitly
169 cognized so that their relations can be worked out, gradually resulting into representations of the
170 next cycle. Therefore, these cycles are distinguished from each other by the type of representation
171 dominating in each (i.e., episodic schemes, mentations, rules, and principles) and the relations
172 connecting representations (i.e., spatially and time-based associations, representational mappings,
173 inferential links, truth- or validity-based inferential constraints) [5, 16].

174 Cognizance is central in this developmental system. It defines the subjective aspect of mental
175 functioning, raising it from simple computation to representation where information and mental
176 functioning is subjectively meaningful. Thus, cognizance is a major source of transitions across cycles.
177 The self-representation system gradually builds pointers to different combinations of (i) problem
178 solving skills and processes, (ii) dispositions to go on with a particular pattern of activity or abandon
179 it, and (iii) feedback received about successes and failures and the ensuing feelings of satisfaction and
180 dissatisfaction. These pointers are used by the person for self-regulation and self-representation,
181 enabling him or her to choose appropriate action patterns among alternatives. Thus, both action
182 patterns and self-representations come out as packages involving combinations of abilities,
183 dispositions, styles, and interests. Cognizance is cycle-specific, exerted through the representational
184 processes dominating in each cycle: it is based on perception- and iconic-like representations in the
185 representational cycle; rule-based inferential processes in the rule-based cycle; and abstract semantic
186 processes in the principle-based cycle. It becomes increasingly accurate along the cycles resulting into
187 increasingly refined understanding of the functioning of the mind and increasingly accurate self-
188 representations, specifying personal strengths and weakness [5, 14-16].

189 *Personality development.* Precursors of adult personality dimensions are established very early in
190 life. Temperament, which reflects differences between children in their reactivity to external stimuli
191 and their ability for self-regulation are present since infancy. For instance, the tendency to
192 independently explore the environment which predates openness and the tendency to become
193 distressed by variations in the environment which predates neuroticism are present from the first
194 months of life [7]. Thus, the Big Five Factors are discernible from early childhood; however, their
195 reliability and stability increase with age [43,44]. Overall, conscientiousness, irritability, and positive
196 activity are present and relatively stable since early childhood; extraversion and neuroticism stabilize
197 after the age of 8 years; openness may not be a meaningful dimension of personality prior to
198 adolescence [45,46].

199 *Interactions between Intelligence and Personality*

200 Some relations between cognitive processes and personality dispositions are well established in
201 the literature. For instance, the positive relation between fluid intelligence and openness is well
202 established [8]. In development, Ziegler [10] showed longitudinally that openness positively
203 influences the development of fluid intelligence from adolescence to early adulthood. There is
204 evidence that open individuals 'see' more possibilities in the input and they flexibly combine
205 information from the two eyes in a creative fashion, especially under a positive mood [47]. Along this
206 line, personality differences influence selective attention to stimuli. McIntyre and Graziano [48]
207 showed that individuals oriented to other persons tend to selectively attend to social stimuli; individuals
208 oriented to inanimate things tend to selectively attend to objects. Finally, there seems to
209 be a negative relation between conscientiousness and intelligence, implying that intelligent
210 individuals are less organized and rule-abiding. Noticeably, however, both conscientiousness and
211 intelligence are positively related to various life outcomes, such as school success, implying that intelligent
212 organizing behaviour in the pursuit of long-term goals may compensate for possible limitations in
213 intelligence [9,39]. Overall, in developmental models of intelligence-personality relations the
214 direction of causality is tilted in favour of personality. Originating from differential rather than
215 developmental theory, the models assume that some personality dispositions allow better
216 "investment" of available cognitive ability in activities conducive to learning thereby increasing
217 intelligence or life achievements [49-51]. Specifically, several investment traits, such as curiosity, need
218 for cognition, novelty seeking, openness to experience, and mindfulness, when high, drive the person
219 to engage in cognitive activities which cause cognitive enhancement.

220 Based on the discussion above, the studies presented here are relevant to the following
221 predictions. First, psychological research accesses cognition and personality at different levels of
222 functioning. Cognitive measures reflect performance as measured by the researcher. Personality
223 measures reflect self-representations of one's own behavioral tendencies or behavior. Therefore,
224 cognition-personality relations may be masked by differences in variation of the two levels involved
225 (actual cognitive tasks vs. self-representations and personal experiences) and differences in
226 measurement accuracy of those involved (the researcher vs. the participant). Hence, correlations at
227 the task and domain level may be low; however, relations between latent constructs capturing general
228 cognitive and personality dimensions would be systematically present, because latent constructs
229 capture mental and behavioral constraints exceeding local task- or experience-related variation.

230 Second, relations between mental processes and personality dispositions would be bidirectional
231 and would strengthen with age, reflecting the increasing consolidation of personally adaptive
232 patterns of understanding and behavior. These relations would reflect the nature of self-
233 understanding and mental complexity possible at the developmental cycle concerned. For instance,
234 cognition-personality relations would be closer in adolescence than in childhood because self-
235 monitoring and self-regulation are more accurate and efficient in the cycle of principle-based thought
236 as compared to the cycle of rule-based thought. Also, in periods of extensive cognitive restructuring
237 cognition-personality relations may strengthen to reflect the transfer of cognitive changes to overall
238 self-representation, self-evaluation, and self-management.

239 Third, given the self-representational nature of personality evaluation, cognizance would
240 emerge as the main link between cognition and personality. This may emerge in several forms. When
241 directly measured, cognizance would emerge as the main mediational construct bridging cognition
242 with personality. When represented by a proxy, such as Eysenck's social likeability or cognitive self-
243 concept as such, which reflect personal value-laden self-representations, relations between the proxy
244 and cognition would be stronger than between cognition and other personal dispositions, such as
245 neuroticism. These differential relations would reflect influences of cognitive change on the fine-
246 tuning of one's self-representation and self-worth vis-à-vis the world.

247 Fourth, some cognitive processes are related with personality processes more than with others
248 and vice-versa. Specifically, executive mental processes, such as attention control, would relate with
249 personality processes reflecting plasticity, such as openness; inferential processes would relate with
250 stability processes, such as conscientiousness and agreeableness, reflecting the fact that these

251 personality dispositions directly use these processes in developing self-organization and social
252 interactive aspects of behavior.

253 Finally, fifth, actual life outcomes, such as academic achievement, would equally relate to all
254 three aspects of dealing with the world, cognitive, personality, and motivational, because all three of
255 them are involved in sustaining long-term behavioral and socially valued goals [9,39].
256

257 **2.1. Study 1: Developmental Changes in Personality-Intelligence Relations**

258 The present study was part of a longitudinal study of cognitive development covering the age
259 span from 9 to 16 years of age (see [52]). The study focused on the development of inductive (fluid)
260 reasoning, deductive syllogistic reasoning, and scientific reasoning underlying the ability to test
261 hypotheses by specifically designed experiments. Participants were tested three times separated by
262 1-year intervals by a specifically designed Raven-like Matrices test, a test of syllogistic reasoning
263 addressed to various logical schemes, and a test of scientific reasoning requiring isolation of variables
264 in designing experiments at several levels of complexity [53]. At the first two testing waves
265 participants were also tested by the Eysenck Personality Questionnaire (EPQ) [54]. Therefore, this
266 study allows testing longitudinally how cognitive changes relate with possible personality changes
267 in the transition from childhood to adolescence.

268 Eysenck's theory of personality specified four factors: extraversion (E), neuroticism (N),
269 psychotism (P), and social likeability (L). We noted above that two of these factors, E and N, are by
270 and large the same with the corresponding factors in the Big Five Factor model. There is less
271 agreement about the rest two. Specifically, P is characterized by aggression, assertiveness, egocentric
272 and manipulative behaviors, orientation to achievement, dogmatism, and tough-mindedness.
273 Notably, Eysenck [19] himself and Costa & McCrae [20], the proponents of the Big Five Factor model,
274 agree that P involves a combination of traits of A and C. Empirical evidence did show that P involves
275 C and Impulsive Sensation Seeking, indicating lack of planning and a tendency to act without
276 thinking [55]. Individuals high in L tend to give positive characteristics to themselves in their
277 relations with others: i.e., that they are considerate, good mannered, and faithful to others, enjoying
278 being with and co-operating with them, follow the rules, and recognize their mistakes. This scale
279 correlates with Impulsive Sensation Seeking [55].

280 Customizing the general predictions stated above to the present study allows testing three
281 specific predictions. First, according to the first prediction about general factors, systematic relations
282 between g and the GFP are expected. Second, according to the second prediction about the direction
283 of cognition-personality interactions, stronger cognition-personality relations are expected in the
284 earlier part of the age period examined here to signify the transition from rule- to principle-based
285 thought from childhood to adolescence. Third, according to prediction about the role of cognizance,
286 a privileged relation of L to cognitive change relative to the other personality dimensions is expected
287 to reflect adjustments in self-evaluation and self-representation associated with this transition.
288 Finally, according to prediction about varying relations between different mental and personality
289 processes, some dimensions, such as P may be negatively linked to cognitive change to reflect relative
290 caution in cognitive engagement which may deprive individuals of possible learning opportunities.
291

291 **2.1.1. Method**

292 *Participants*

293 A total of 260 participants were examined longitudinally, covering the age span from nine to 16
294 years. Specifically, this total included 44 4th grade primary-school children (mean age 9.6 years old at
295 first testing; 31 males), and 46 (mean age 12.6 years at first testing; 21 males), 92 (mean age 13.6 years
296 at first testing; 46 males), and 78 (mean age 14.6 years at first testing, 31 males) 1st, 2nd, and 3rd grade
297 secondary school students, respectively. All cohorts were tested three times by the cognitive battery
298 and two times by the EPQ (in March or April) separated by one-year intervals. Participants lived in
299 Thessaloniki, the second largest city in Greece, and came from middle or high SES families.
300

300 *Task Batteries*

301 The fluid reasoning battery included 12 Raven-like matrices specifically designed to address the
302 following four levels of complexity: (i) integration of two attributes varying in the same direction

303 (e.g., geometric figures of increasing size and with a background mark increasing in the same
304 direction); (ii) integration of intersecting elements, such as size and shape, marked by elements such
305 as dots at a particular position, without transformations; (iii) dissociation of relevant from irrelevant
306 elements or simple transformations such as the rotation of a line across matrices; and (iv) integration
307 of multiple properties varying according to several rules (e.g., change in shape, size and position of
308 some attribute).

309 *The deductive reasoning battery* included 20 items addressed to different types of logical relations
310 scaling in four levels: (i) Modus ponens (implication) and disjunctive reasoning; (ii) modus tollens
311 and falsification of disjunctive propositions; (iii) understanding of arguments of falsification and
312 grasp of non-decidability of arguments; (iv) explicit grasp of the rules of implicative reasoning and
313 full mastery of fallacies (affirmation of the consequent and denial of the antecedent).

314 *The scientific reasoning battery* included 16 items addressed to the following four levels: (i) identification
315 of confounding variables and interpretation of the results of simple experiments (matching variables with their effects); (ii) systematic isolation of variables of explicit hypotheses; (iii) design
316 experiments verifying a hypothesis and interpretation of evidence suggesting various causal
317 relations (necessary and non-sufficient; neither necessary nor sufficient; incompatible); (iv) design
318 experiments (i) to falsify a hypothesis, (ii) verify each of the above causal relations, and model
319 construction.

320 The full version of the *Eysenck Personality Questionnaire* (EPQ) was used. EPQ involves 80 items
321 addressed, 20 for each four personality dimensions specified in Eysenck's theory [17].

322 *Scoring*

323 All items in the cognitive batteries were scored on a pass-fail basis. To pass a matrix, two empty
324 cells (the second and third cell of the second and third raw, respectively) would have to be filled in
325 by choosing the proper options among 8 alternatives. To pass a syllogism, the logically proper answer
326 would have to be selected among three alternatives. To pass a scientific reasoning item answers
327 would have to indicate task-relevant control of variables, hypothesis formation, or data
328 interpretation.

329 A level score was given to each participant for each battery; this is the highest level at which a
330 person solved two thirds or more of the tasks at this level. The level structure of each battery was
331 validated and fine-tuned by means of Discrimination Level Analysis. This method was developed by
332 Shayer to score individual performance on batteries involving developmentally scaled tasks [56]. This
333 method showed that the four-level sequence proved very consistent for each battery. In concern to
334 the developmental cycles summarized in the introduction, the first two levels of the inductive and
335 deductive reasoning batteries addressed early and late rule-based thought and the last two addressed
336 principle-based thought. Level I of the scientific reasoning battery addressed late rule-based thought;
337 level II addressed early principle-based thought; levels III and IV addressed late-principle-based
338 thought. Thus, a level score, ranging from 0 (not satisfying ascription to the lower level of a scale) to
339 4 was ascribed to each person for each battery at each testing wave. These scores were used in the
340 various analyses to be presented below. All three batteries were very reliable (Cronbach's alpha
341 always $> .8$; mean inter-rater agreement for the scientific reasoning battery was 85.2%, $sd = 9.7$).
342 Within battery correlations of level scores across waves were high (.45-.67); correlations across
343 batteries were lower, but still high (.29-.56).

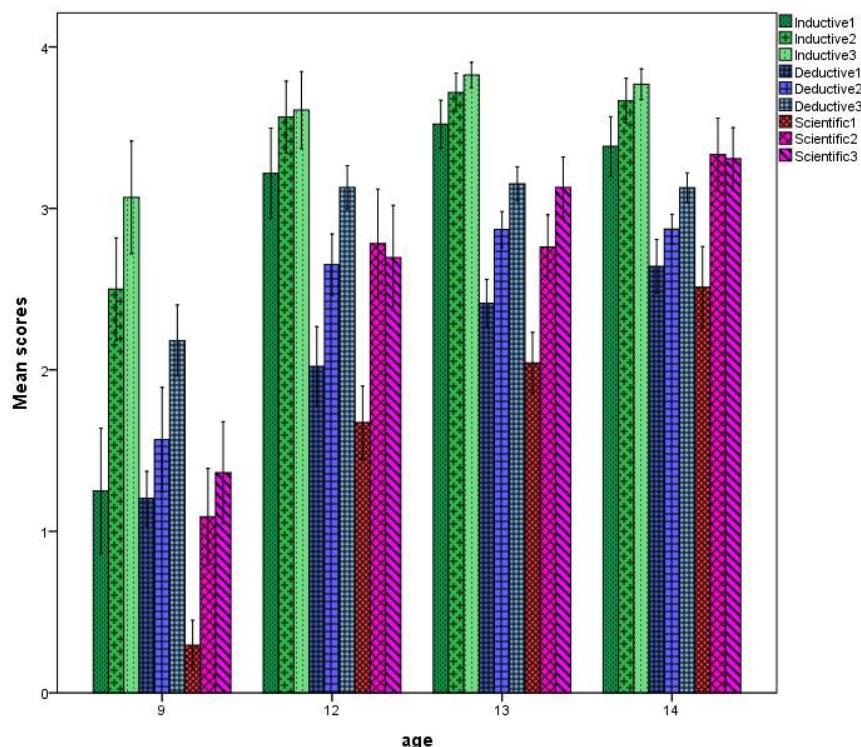
344 Responses to the items in the EPQ were identified as yes/no (applies vs. does not apply to me)
345 and the participant's score on each dimension was the sum of the items judged to apply. Cronbach's
346 alpha was marginally satisfactory if estimated at each testing wave (.51 and .47 for first and second
347 testing, respectively); however, it was high if the reliability of the two testing waves was estimated
348 together as used in the structural equation models tested (.75). Self-correlations across waves were
349 very high: .72 – .85; N and P correlated positively with each other within and across waves (.18 –
350 .22); E correlated positively with P (.11 – .13) and negatively with N (-.13 – -.15); L correlated highly
351 and negatively with P and N (-.39 – -.49) and negatively but low with E (-.05 – -.09). Correlations
352 of three personality dimensions (E, P, and N) with the three cognitive scales were low to moderate
353 (.00 – .26); the correlations of L with the three cognitive dimensions were much higher, but always

355 negative (-.22 — -.45), suggesting a systematic developmental relation (see correlations in Table A1,
 356 in the Appendix).

357 **2.1.2. Results**

358 The pattern of performance on the cognitive tests is shown in Figure 1. The effect of age, $F(3, 252) = 120.415$, $p < .0001$, partial $\eta^2 = .59$, was highly significant and very powerful, reflecting large
 359 improvement of performance across age groups. The effect of testing wave was also significant, $F(2, 251) = 238.813$, $p < .0001$, partial $\eta^2 = .66$, reflecting large improvement across testing waves. The effect
 360 of cognitive domain was also highly significant, $F(3, 251) = 259.668$, $p < .0001$, partial $\eta^2 = .67$, reflecting
 361 variation of performance across domains: performance on inductive reasoning was higher than on
 362 deductive reasoning and this was higher than scientific reasoning. The interactions between age and
 363 wave $F(6, 504) = 7.732$, $p < .0001$, partial $\eta^2 = .08$, and wave and domain, $F(4, 249) = 7.756$, $p < .0001$,
 364 partial $\eta^2 = .11$, were also significant, indicating two trends: first, the magnitude of improvement
 365 across waves varied with age; it was much larger at lower ages, indicating transition from rule-to
 366 principle-based thought and approaching ceiling at older ages; second change was almost linear
 367 across domains in inductive and deductive reasoning but larger from first to second than from second
 368 to third in scientific reasoning. Noticeably, no effect of gender ever reached significance.

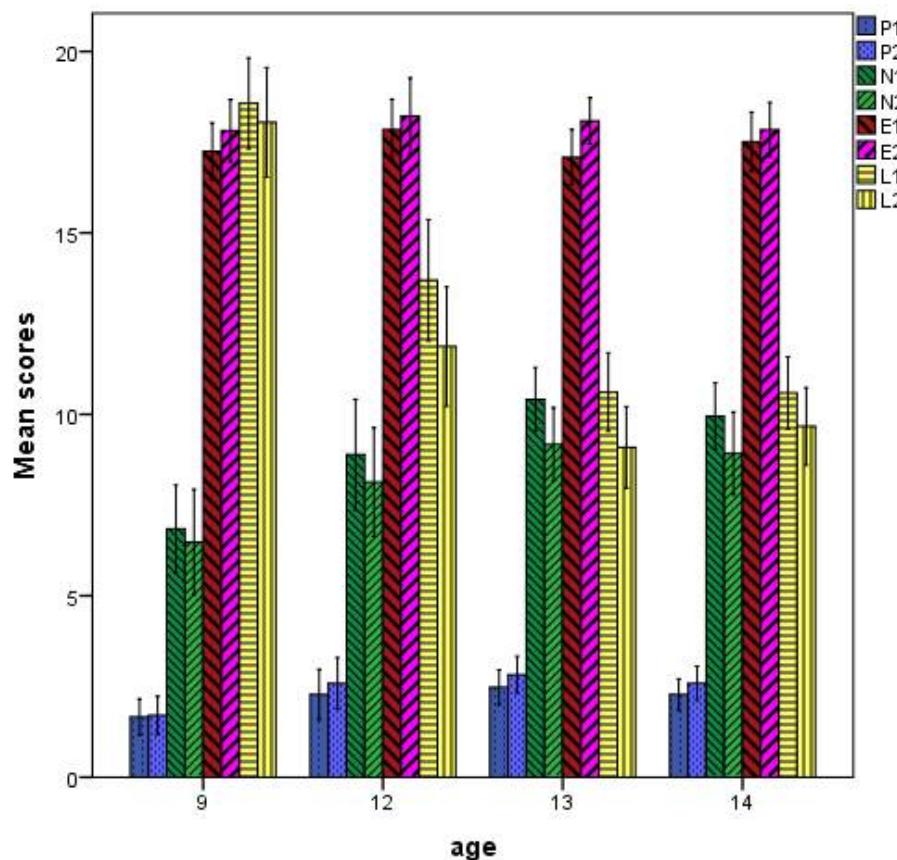
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372
 373 Figure 1. Performance on the three cognitive batteries across age and testing waves.
 374

375 There were similarities and differences in the pattern of relations between age, testing wave, and
 376 personality dimensions. Specifically, the effect of age, $F(3, 256) = 9.307$, $p < .0001$, partial $\eta^2 = .10$;
 377 wave, $F(1, 256) = 15.390$, $p < .0001$, partial $\eta^2 = .06$, and dimension was significant, $F(3, 254) = 1811.559$,
 378 $p < .0001$, partial $\eta^2 = .96$. Also, the age by dimension, $F(9, 768) = 8.264$, $p < .0001$, partial $\eta^2 = .09$, and
 379 the waves by dimension interaction was highly significant, $F(3, 256) = 28.287$, $p < .0001$, partial $\eta^2 =$
 380 .26, indicating that the relation with age differed across dimensions. Figure 2 illustrates these effects:
 381 P and N increased across the first three age groups and decreased at the last age group; scores in E
 382 increased from 9 to 11 years, decreased from 11 to 13 and then increased again; scores in L decreased
 383 across the first three age groups and stabilized there. Across waves, P and E increased; N and L
 384 decreased. Thus, in line with our first prediction, changes in personality were larger earlier in age,
 385 largely reflecting patterns of cognitive change.

386



387

388

389 Figure 2. Personality scores across age, testing wave, and personality dimensions.

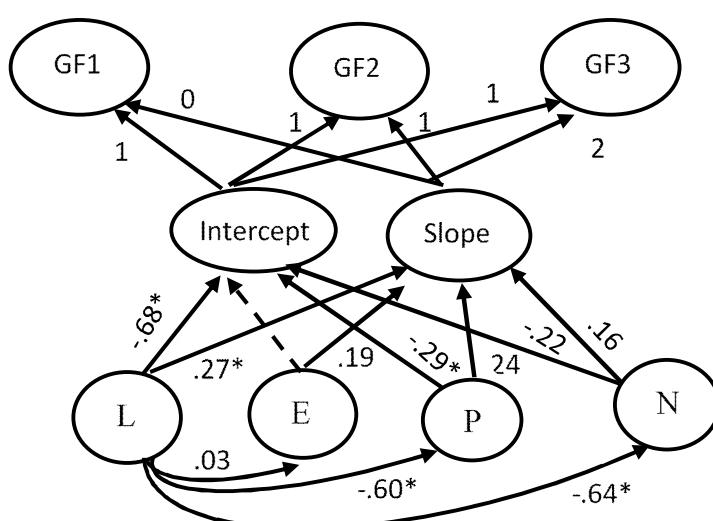
390

391 **2.1.3. Cognition-Personality Relations with Development**

392 Three approaches were adopted to specify the relations between changes in mental and
 393 personality processes. First, a series of confirmatory factor analyses examined the robustness of
 394 cognitive and personality factors and if these factors are related. A first pair of models focused on
 395 performance at first testing. In this model, performance on inductive, deductive, and scientific
 396 reasoning at first testing were related to one factor standing for Gf and the scores on the four
 397 personality factors at this testing were related to another factor standing for the GFP. In the first of
 398 the two models the correlation between these two factors was constrained to 0 ($\chi^2(14) = 115.79$, CFI =
 399 .76, $p < .001$, RMSEA = .168, AIC = 87.79). In the second model, the correlation of the two factors was
 400 left free to be estimated, ($\chi^2(13) = 38.54$, CFI = .94, $p < .001$, RMSEA = .087, AIC = 12.54). The fit
 401 difference between the two models was significant, $\Delta\chi^2(1) = 77.25$, $p < .001$, reflecting the fact that the
 402 two factors were significantly correlated (.59) (see Study 1, Model 1, in Supplementary Material
 403 presenting model codes and complete solutions). The pattern of results obtained from the models
 404 applied to the second testing wave were practically identical with those of the first testing. It is
 405 notable, however, that the same pattern emerged when this approach was applied on the
 406 performance attained at all testing waves. Specifically, in this model, a Gf factor was created for each
 407 of the three testing waves associated with performance on inductive, deductive, and scientific
 408 reasoning at the respective wave. In the same fashion, a GFP of personality was created for each of
 409 the first two testing waves, associated with the scores on each of the four personality factors at the
 410 respective wave. The three wave-specific Gf factors were regressed on one second-order factor and
 411 the two wave-specific personality factors were regressed to another second-order factor. In a sense,
 412 then, these two factors stand for diachronic cognitive ability and personality operating regardless of
 413 developmental changes in each of them, in the time-window covered by this study. Therefore, it is

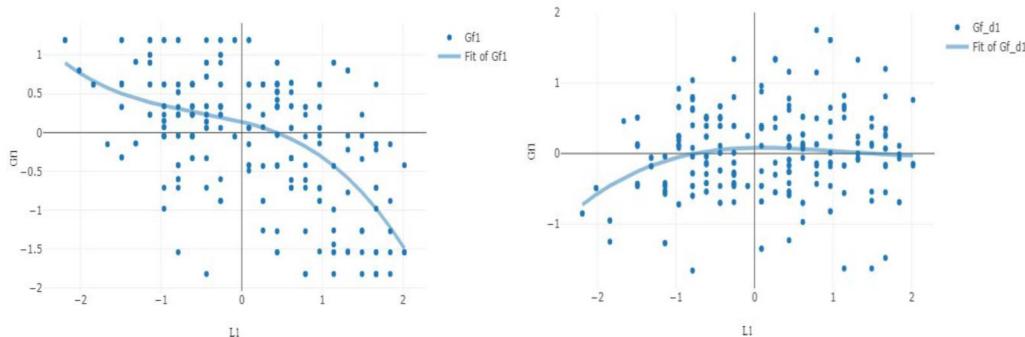
414 highly interesting and relevant to the analyses to follow to specify how these factors are related. In
 415 the fashion above, in the first model, the correlation between the two diachronic factors was
 416 constrained to be 0, (χ^2 (105) = 293.64, CFI = .92, $p < .001$, RMSEA = .084, AIC = 83.64). In the second
 417 model, this correlation was left free to be estimated, (χ^2 (104) = 213.72, CFI = .95, $p < .001$, RMSEA =
 418 .064, AIC = 5.72). The difference between the fit of the two models was significant, $\Delta\chi^2$ (1) = 79.92, p
 419 < .001, reflecting the fact that the two factors were highly correlated (.76). Notably, when this second
 420 model was estimated after partialling out the effect of age from each score-factor relation involved,
 421 the model still held well, (χ^2 (104) = 200.40, CFI = .96, $p < .001$, RMSEA = .060, AIC = -7.60); the
 422 correlation between the two factors dropped but it was still significant and high, (.48). Therefore, in
 423 line with the first prediction about general factors, cognition and personality are systematically
 424 related in the period from 9 to 16 years and this interaction is developmentally sensitive to
 425 developmental influences. The models below will specify the sources of these interactions.

426 Second, a growth model examined the possible influence of personality on the form of cognitive
 427 development in the three years covered by this longitudinal study. This model is shown in Figure 3.
 428 It may be seen that all three cognitive scores of each testing wave were related to a wave-specific Gf
 429 factor. The relation between these three factors and the intercept was constrained to unity to capture
 430 the initial mean of the growth function. To specify the degree of change across the three testing waves,
 431 the relation between the three wave-specific factors and slope was constrained to 0, 1, and 2,
 432 respectively. To specify the possible distinct influence of personality on the intercept and slope, P, N,
 433 and E were regressed on L, thereby raising L to a background factor standing for the GFP (see Fig. 3).
 434 The intercept and slope of Gf were regressed on L and the *residuals* of each of the other three
 435 personality factors. This manipulation allows to distinctly specify the effects of L and each of the
 436 other three personality factors on the two Gf growth parameters, after removing any likeability
 437 possibly involved in them. The fit of this model was very good, Satorra-Bentler χ^2 (12) = 16.27, CFI =
 438 .965, $p = .180$, RMSEA = .071. It may be seen that the intercept was negatively and highly related to
 439 the L factor (-.68) and moderately but significantly to the P (-.29) and the N (-.21). These effects suggest
 440 that initial high scores in L but also in factors reflecting low emotional stability are associated with
 441 comparatively lower cognitive performance.
 442



443
 444
 445 Figure 3. The growth model of Gf with personality effect on Gf intercept and slope.
 446 Note: See the full model in Supplementary Material (Study 1, Model 2) presenting model codes and
 447 complete solutions).
 448

449 However, the relation of personality factors with slope was significant and positive (.27, .17, .24
 450 for L, E, and P, respectively). This implies that initial high scores in these factors were associated with
 451 larger cognitive change.



452
 453 Figure 4. Relations between Gf and L (Panel A, $R^2 = .39$) and change in Gf from first to second testing
 454 wave with L (Panel B, $R^2 = .07$).
 455

456 Third, to further specify these relations, Latent Transition Analysis (LTA) was employed [57].
 457 LTA specifies how individuals move across categories in a period of interest and the factors possibly
 458 affecting this movement. Here the first two waves were involved. Two categories were specified, one
 459 for cognitive performance at first wave and one for cognitive performance at second wave. The level
 460 score of each of the three cognitive abilities at each testing wave were used. There were two classes
 461 of participants in each category: those changing into a higher level and those staying on or regressing
 462 from their initial level. The mean score on each of the four personality factors were involved as
 463 covariates to examine how personality factors affect transition to a higher level across the first two
 464 testing. Practically, we regressed transition to a higher level across the two waves on these personality
 465 scores to examine how they influence the likelihood of change.

466 This model accounted well for the patterns of performance observed (Pearson Chi-Square
 467 (15526) = 2537.66, $p = 1.0$; Likelihood Ratio Chi-Square (15526) = 773.224, $p = 1.0$; Entropy = .88). The
 468 probability of moving to a higher level was higher (.54) than staying to the same level (.46) (odds to
 469 progress was 1.17). Of the various covariates, only L exerted a significant influence on transition (2.33,
 470 $p < .0001$; odds 10.24) (see Study 1, Model 3, in Supplementary Material). Overall then, in line with
 471 the third prediction about cognizance, higher scores in L at the start were associated with transition
 472 to a higher cognitive level. It is noted, however, that despite this overall relation, the cubic relation
 473 between cognitive attainment and the product of age by social likeability suggests that early in age
 474 (from late childhood to adolescence) it is more likely to change when L is lower rather than higher
 475 than latter in age (after the age of 12 years). To model this relation, age was included as a covariate
 476 in the model, in addition to the personality scores. Indeed, in this model, individuals with higher L
 477 scores were 4.28 times more likely (1.46, $p < .002$) to stay at the initial level rather than transition to a
 478 higher level as compared to individuals with lower likeability scores. This might imply that at the
 479 transition from childhood to adolescence lower likeability scores reflect a stricter and more accurate
 480 cognitive self-representation, implying more advanced transition possibilities. Figure 4 illustrates this
 481 pattern of relations from first to second testing: Panel A shows the negative relation between Gf and
 482 L ($R^2 = .39$); panel B shows that higher L scores associated with increases in Gf from first to second
 483 testing (expressed as the difference between first and second testing scores) especially at initially
 484 lower cognitive ability levels ($R^2 = .07$).

485 Normally, the findings above imply that changes in personality are associated with the state of
 486 one's cognitive ability. To explore this possibility, the model above was inverted so that possible
 487 cognitive influences on personality changes would be captured. In this model, personality scores on
 488 the four dimensions at each testing wave were associated to two categories, staying and changing,
 489 and Gf attainment was used as the covariate to specify if personality changes across waves are
 490 affected by the initial stage of Gf. Indeed, as expected based on the results above, there was a rather
 491 small but significant effect of initial cognitive attainment on personality: those starting higher on Gf
 492 were more likely to evidence personality changes both from first to second and from first to third

493 testing (1.03, $p < .002$; odds 2.80); lower personality scores were associated with higher likelihood for
494 staying unchanged from first to third testing (-1.58, $p = .02$; odds = .20) (see Study 1, Model 4, in
495 Supplementary Material).

496 In conclusion, the patterns of relations described above are in line with predictions. L, par
497 excellence, at an earlier time did predict cognitive change and the state of cognition did predict
498 changes in personality. Three interpretations may be given to this combination of patterns. A
499 cognitive explanation would suggest that individuals starting lower in cognition have more room for
500 change. Personality factors, being negatively associated with cognitive attainment, reflect, to some
501 extent, that individuals obtaining extreme scores on personality dimensions are more likely to change
502 cognitively because of their distance from cognitive ceiling. A personality explanation would suggest
503 that individuals high in likeability are involved in a positive loop motivating them to advance
504 cognitively to sustain their positive self- or social image. Finally, a moderate degree of psychoticism
505 is related to higher cognitive achievements. A third interpretation would integrate the two
506 interpretations above into one: changes in self-monitoring and self-regulation processes associated
507 with the transition from rule- to principle based-thought tune cognitive functioning and self-
508 presentations so that they more accurately reflect each other. The studies below will further highlight
509 these relations.

510 511 2.2. Study 2: Transition from Rule- to Principle-Based Thought and the Big Five Factors 512

513 This study covered rule-based and principle-based thought, involving participants from 7
514 through 17-year of age. Study 1 above involved only fluid inferential cognitive processes and
515 personality. This study involved, additionally, executive processes, such as attention control and
516 working memory, and crystallized cognitive processes, such as mathematical reasoning. The
517 translated Croatian version of the 50-item IPIP Big Five inventory [58] was given at the beginning of
518 the second testing. Involving the Big Five Factors allows a more refined mapping of personality
519 processes. Participants were examined twice by the cognitive tests and once by the personality test.
520 Thus, this study may help differentiate possible influences of personality on changes in Gf from the
521 possible effects of executive processes.

522 Customizing our general predictions to the present study, we would expect the following
523 patterns of relations: First, the Five Factors are hierarchically organized into the stability and
524 plasticity factors which relate to the GFP. Second, according to the first of the predictions stated in
525 the introduction, the g and the GFP are related. Third, executive cognitive processes would relate
526 more to the plasticity factors in personality; fluid and crystallized cognitive processes would relate
527 more to the stability factors. Finally, according to our fourth prediction in introduction, stability
528 factors would impede but plasticity factors would facilitate development of inferential abilities.

529 2.2.1. Method

530 Participants

531 A total of 438 right-handed participants from 7 through 17 years of age (206 male) were involved.
532 At first testing, they were 7.92- (15, 12 males), 8.53- (68, 39 males), 9.33- (61, 34 males), 10.73- (21, 5
533 males), 11.39- (53, 30 males) 12.73- (38, 18 males), 13.30- (52, 28 males), 14.77- (20, 12 males), 15.41-
534 (42, 19 males), 16.61- (35, 17 males), and 17.29-years-old (35, 18 males), respectively. These
535 participants were all native speakers of Croatian and lived in Zagreb, Croatia's capital. They were
536 students in Croatian public schools and thus SES is about equally represented in each age group.

537 Tasks

538 All cognitive tests used here are described in Žebec, Demetriou, and Kortla-Topić [59].
539 Specifically, the MID-KOGTESTER1 was used to test speed of processing, selective and divided
540 attention. This is a computer-based test battery that contains eight cognitive tests. For processing
541 speed, participants responded to the appearance of stimulus (six same color Xs) by lifting their finger
542 from a resting key to touch the target as fast as possible. In choice reaction tasks, participants
543 responded to one of four target stimulus by pressing the appropriate (one of four) response key. For
544 attention control, a Stroop-based task was used: participants responded to the ink color of congruent

545 and incongruent of color words denoting the same or a different color. The Stroop effect, which is the
546 difference in RT between incongruent and congruent tasks, is regarded as a measure of selective
547 attention [60-61]. The *divided attention* (DA) task demanded simultaneous responding to two different
548 tasks on the two panels, where the stimuli were presented in fast succession (50 to 250 ms). Task 1
549 was a simple reaction time task from the SRT-LH test. Task 2 is an object size classification task from
550 the OSC test, made in the form of two-choice RT task [60]. Participants were asked to respond to Task
551 1 with the left hand on Panel 1, and on to Task 2 with the right hand on Panel 2. The difference
552 between RT on Task 2 performed together with the Task 1 and RT on Task 2 performed separately
553 was used as a measure of divided attention [61]. Test-retest reliability (across the two testing waves)
554 was high, varying between .7 (CRT-C) and .85 (DA).

555 Working memory was addressed by the forward (FDS) and backward (BDS) digit span tasks
556 included in the WISC-III test and extended with two items in FDS and one item in BDS (in order to
557 increase discriminability of older age groups). Test-retest reliability across the two testing waves was
558 satisfactory both for the FDS (.69) and the BDS (.66).

559 Mathematical reasoning was addressed by tasks examining the ability to execute arithmetic
560 operations in combination to each other, algebraic reasoning, and proportional reasoning. Items in
561 each domain scaled along four levels. In the arithmetic tasks, participants were asked to specify the
562 operations missing from simple arithmetic equations: One (e.g., $5 * 3 = 8$), two (e.g., $\{4 \# 2\} * 2 = 6$),
563 three (e.g., $\{3 * 2 \# 4\} @ 5 = 7$), and four operations (e.g., $\{5 @ 2\} o 4 = \{12 \$ 1\} * 2$) were missing from the
564 items of each level. The algebraic reasoning tasks required to specify one or more unknowns in an
565 equation (e.g., $a + 5 = 8$, specify a ; $u = f + 3$; $f = 1$; specify u ; if $(r = s + t)$ and $(r + s + t = 30)$, specify r ;
566 when is true that $\{L + M + N\} = \{L + P + N\}$ for the four levels, respectively). In proportional reasoning,
567 the four levels required to grasp relations between the following: (i) fully symmetrical and equivalent
568 ratios (e.g., $1/2$ to $3/6$); (ii) equivalent but not obviously symmetrical ratios (e.g., $2/6$ to $3/9$); (iii) ordered
569 pairs with two corresponding terms multiple of one another (e.g., $2/5$ to $3/7$); (iv) pairs without
570 corresponding terms (e.g., $5/12$ to $3/8$). In terms of the cycles of development specified in the
571 introduction, the two lower levels of these batteries are primarily related to the two phases of the
572 rule-based concepts. Levels three and four addressed the two phases of the principles cycle,
573 respectively. This battery was found to have good psychometric and developmental properties in
574 several studies [26]. In the present sample *discriminability* (average index of difficulty of 35 tasks is .52
575 and Ferguson's Δ is .98) and *reliability* were high (Cronbach $\alpha = .92$, split-half = .95).

576 Raven's Standard Progressive Matrices involve five sets of matrices of increasing complexity.
577 Based on Rasch scaling of performance on each of the 60 matrices, four levels were formed, each
578 involving 15 matrices. From easy to difficult, matrices in the first group, require grasping the pattern
579 underlying figures varying along a single dimension. In the second group, two familiar and obvious
580 dimensions (e.g., shape, size, background, etc.) would have to be integrated. In the third group,
581 matrices require deciphering and integrating critical dimensions through systematic search and
582 transformation of the features involved. For instance, it is the double of ..., it goes by one more, etc.
583 Finally, in the fourth group, matrices require deciphering multiple dimensions by grasping the thread
584 underlying several transformations of figures and integrating into complementary general principles.
585 Level 1 addresses abilities of the second phase of the representational cycle. Levels 2 and 3 address
586 abilities associated with the two phases of rule-based thought, respectively. These were the levels
587 represented in the Raven-Like test used in Study 1. Level 4 addresses abilities of first level of
588 principle-based thought.

589 The translated Croatian version of the 50-item IPIP Big Five inventory included 50 items, 10 for
590 each of the Big Five Factors. This inventory was highly reliable (Cronbach alpha = .83).

591 The correlations between reasoning tasks were very high (.5-.7). Correlations between
592 personality measures were lower but significant (all but one .2-.3). Correlations between cognitive
593 and personality measures varied according to personality dimension: they were positive and
594 moderate but mostly significant in the case of E (circa .2) and negative in the case of C (circa -.2); the
595 rest varied between 0-.2 (see correlations in Table A2, in the Appendix).

596 2.2.2. Results

597 *Development.* Figure 5A-C shows the developmental pattern of cognitive processes as a function
 598 of age at first and second testing wave. There were very large changes across all cognitive processes.
 599 Overall, in the cognitive domain, children progressed from modal level 1 at 7-8 years of age to modal
 600 level 3 at 16-17 years of age, $F(10, 421) = 136.09$, $\eta^2 = .76$. Moreover, there was significant progress
 601 across all mental processes and across all age groups, $F(1, 427) = 269.76$, $\eta^2 = .39$, from first to second
 602 testing. The significant interactions between age and domain, $F(30, 1281) = 13.96$, $\eta^2 = .25$, and age and
 603 testing wave $F(10, 427) = 4.24$, $\eta^2 = .09$, as well all three factors, $F(30, 1281) = 2.66$, $\eta^2 = .06$, indicated that
 604 the degree of change across age or wave differed across cognitive processes. It is noted that different
 605 domains spurted and consolidated at different age phase. It can be seen that arithmetic reasoning
 606 spurted from 7 to 11 years of age, indicating, that it is basically a rule-based acquisition; algebraic
 607 reasoning demonstrated very little change from 7 to 11 years but developed very fast between 11 and
 608 14 years, obviously reflecting its principle-based origins; interestingly, performance on Raven
 609 matrices developed in two spurts, one from 8 to 10, and another from 13 to 15 years, indicating that
 610 it involves a rule-based component and a principle-based component as expected. These patterns are
 611 informative for the cognition-personality relations to be presented below.

612 In concern to personality, the main effect of age, $F(10, 425) = 1.92$, $p < .05$, partial $\eta^2 = .04$,
 613 personality, $F(4, 422) = 37.45$, $p < .0001$, partial $\eta^2 = .26$, and their interaction, $F(40, 1700) = 2.78$, p
 614 < .0001, partial $\eta^2 = .06$, were significant (see Figure 5D). Overall, scores in A exceeded and scores in
 615 N lagged behind all other factors, perhaps reflecting the two poles of social likeability, respectively.
 616 However, differences varied with age: E increased systematically from 7 to 16 years; A increased from
 617 7 to 9 and stabilized; conscientiousness was basically steady from 7 to 10 and then decreased
 618

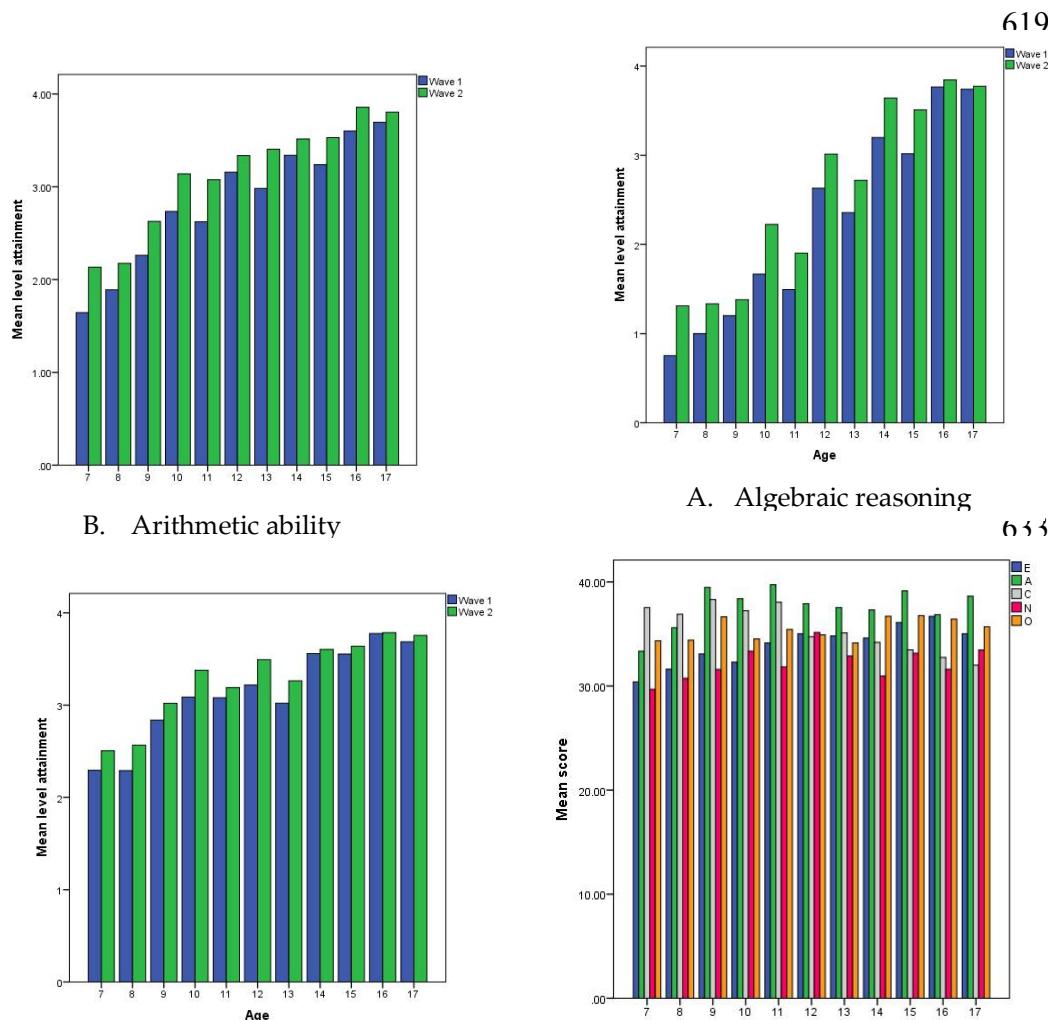


Figure 5. Mean Level Attainment in arithmetic, algebraic, and Raven reasoning (Panels A, B, C) and personality (Panel D) as a function of age and testing wave.

649 throughout the remaining period, resembling the inverse
650 relation between age and L observed in Study 1; N increased from 7 to 10 and then wavered; O
651 wavered throughout, with two noticeable spurts between 8 and 9 and 13 and 14. Overall, increases
652 in personality scores occurred from 7-10 years and decreases occurred in adolescence, possible
653 reflecting the differential effect of acquiring rule-based and principle-based thought. The models
654 below will highlight this developmental intertwining between cognitive and personality processes.

655 *Personality Structure and g-GFP Relations*

656 A first set of models examined the organization of the personality factors, involving three scores
657 parceling the ten items addressed to each factor. These models showed that a three-level hierarchical
658 model was superior to any other model tested. In this model, the first-order factors for A, C, and N
659 were related to a second-order stability factor and the first-order factors for E and O were related to
660 a second-order plasticity factor; these second-order factors, in turn, were related to a third-order GFP.
661 To specify if g and the GFP are related, the approach used in Study 1 was employed here. In sake of
662 this aim, the cognitive factors were also included in the model. Specifically, this model involved the
663 following first-order factors for performance on cognitive processes at the second testing wave which
664 was close in time to the measurement of personality: a factor standing for processing speed was
665 related to two RT scores requiring perceptual discrimination where no interference was involved; a
666 factor standing for attention control was related to three scores addressed to divided and selective
667 attention; a factor standing for working memory was related to forward and backward digit span; a
668 factor standing for Gf was related to the five scores attained on the five sets of Raven matrices; a factor
669 standing for mathematical reasoning was related to the mean performance attained on arithmetic,
670 algebraic, and proportional reasoning tasks; these four cognitive factors were related to a second-
671 order cognitive factor. For personality, a mean score for each of the Big Five was involved; as above,
672 A, C, and N were related to a factor standing for stability and E and O were related to a factor standing
673 for plasticity; these two factors were related a second-order GFP. Following the approach adopted in
674 Study 1, in a first model, the correlation between the second-order cognitive factor and the GFP was
675 constrained to be 0, ($\chi^2 (162) = 622.23$, CFI = .90, $p < .001$, RMSEA = .081, AIC = 298.23); in a second
676 model, these two factors were left free to correlate, ($\chi^2 (161) = 600.28$, CFI = .91, $p < .001$, RMSEA =
677 .079, AIC = 278.28). The difference between the two models was significant, $\Delta\chi^2 (1) = 21.95$, $p < .001$,
678 reflecting the fact that the two factors were significantly correlated (.35). This model is fully presented
679 in Supplementary Material, Study 2, Model 1). This relation dropped but stayed significant after
680 partialling out the effect of age from each measure-factor relation (.26). Also, this relation stayed in
681 the same range when the general cognitive factor was broken into an executive efficiency factor,
682 related to speed and attention control (.36) and a representational efficiency factor, including working
683 memory and the two reasoning factors (.31). These findinngs are in agreement with our second
684 prediction.

685 *Personality Mediation*

686 A second set of models tested how cognitive processes from first testing wave influenced
687 personality measures one year later and how personality measures influenced cognitive measures at
688 second testing. Specifically, this model involved the four first-order cognitive factors involved in the
689 model above; the speed and attention control factors were associated to an executive efficiency factor;
690 the working memory, mathematical reasoning, and Gf factors were associated to a factor standing
691 for representational and inferential power (RIP). It is noted that this factor is narrower than
692 psychometric g because it does not include speed and attention control measures but broader than
693

694

695 A

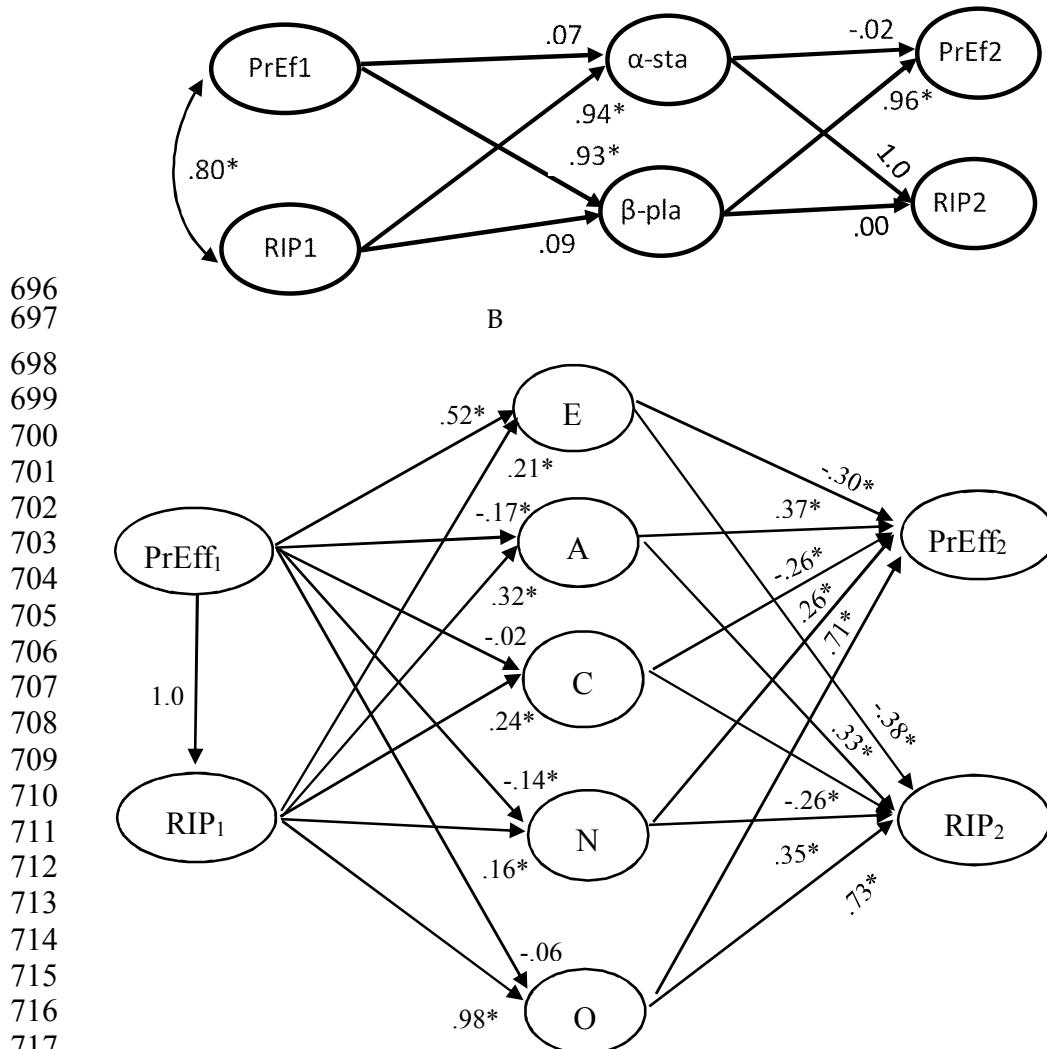


Figure 6. Cross-lagged model of the mediation of personality factors of stability (α -factor) and plasticity (β -factor) between processing efficiency (PrEf) and representational and inferential power (RIP) at first and second testing wave (1 and 2).

Note: Model A and Model are fully presented in Supplementary Material, Study 2, Models 2 and 3, respectively).

psychometric Gf because it includes, in addition to psychometric Gf (the Raven test), working memory and mathematical reasoning; this model also included the three of the Big Five factors, i.e., A, C, and N, related to stability of personality, the α -factor, and the other two of Big Five factors, i.e., E and O, associated with plasticity of personality, the β -factor. The following structural relations were built in this model. On the one hand, each of the Big Five factors was regressed on the two first wave second-order factors standing for processing and representational efficiency, to capture how first wave cognitive processes influenced personality dimensions. On the other hand, each of the two second wave cognitive factors were regressed on the two personality factors, the α -factor and the β -factor. Corresponding measurement errors across waves were correlated. To examine equivalence of factors across waves, the model was tested under the constraint that corresponding measurement-factor relations were free to vary or equal across testing waves.

Notably, the fit of the constrained model, χ^2 (544) = 1839.87, $p > .001$, RMSEA = .074, model AIC = 751.87, was acceptable and better than the fit of the unconstrained model, χ^2 (536) = 2060.84, $p > .001$, RMSEA = .081, model AIC = 988.84. This is the model shown in Figure 6A. The pattern of relations was very interesting: the α -factor, stability, was very strongly related to RIP (.94) and very weakly to processing efficiency (.07); plasticity, the β -factor, demonstrated the inverse pattern of relations: it was weakly related to RIP (.09) but strongly to processing efficiency (.93). This pattern of relations

741 was replicated in the effects of personality on cognitive performance at second wave: plasticity
742 influenced processing efficiency (.96) but not stability (-.02); stability influenced RIP (1.0). These
743 relations were further probed in a model where personality factors were individually involved
744 (Figure 6B). In this model, processing efficiency at first testing was significantly related to E (.52), A
745 (-.17), and N (-.14); RIP at first testing was significantly related to all Big Five factors; notably,
746 however, only its relation with O was very high (.98); the rest were moderate (~.2-.3). Interestingly,
747 all Big Five factors related significantly with both cognitive factors at second testing. Again the
748 relations of all but O with each of these two cognitive factors varied circa .3; the relation of O with
749 both cognitive factors was very high (~.7); attention is drawn to the negative relation of C with both
750 second-testing cognitive factors. It is suggested, in agreement with our third prediction, that
751 personality interacts developmentally with cognition at both the level of individual Big Five factors
752 and the level of more general factors representing stability and plasticity, with A and O to be the
753 factors leading these two general personality orientations.

754 Latent Transition analysis was again used to specify how personality is related to cognitive
755 transition to a higher level. In this analysis level attainment on the three mathematical reasoning
756 batteries and RPM at the two testing waves was used in the model. Specifically, level attainment at
757 first testing on each of these cognitive dimensions was related to one category and level on each
758 dimension at second testing was related to a second category. There were two classes in each
759 category, those staying at the initial class and those changing, either moving to a higher class
760 (category 1) or regressing to a lower class (category 2). At a first test of the model, attention control,
761 working memory, and stability (α -factor), and flexibility (β -factor) of personality were used as
762 covariates. This model fit the data very well (Pearson Chi-Square (199864) = 4015.07, $p = 1.0$;
763 Likelihood Ratio Chi-Square (199864) = 1236.704, $p = 1.0$; Entropy = .88; AIC = 6439.75). The probability
764 of moving to a higher level was good (.46) although lower than staying to the same level (.54) (odds
765 to progress was .84). All four covariates significantly affected transition: the effect of attention control
766 was huge (4.85, $p < .001$; odds = 128.14); the effect of working memory (1.06; $p < .001$; odds = 2.9) and
767 plasticity of personality (β -factor; $p < .04$; odds = 2.11) (.74) was significant and considerable; the effect
768 of stability (α -factor) (-.76; $p < .005$; odds = .47) was significant but negative. In concern to personality,
769 these effects suggest that individuals high in flexibility were 2.11 times more likely to transition to a
770 higher level from first to second testing than to stay at their first testing initial level. On the contrary,
771 individuals high in stability were .47 times more likely to stay at their initial level than progress to a
772 higher level. To further probe the origins of these effects, a second model was tested where the two
773 personality general factors were dropped as covariates and conscientiousness and openness were
774 used in their place. This model fit the data equally well, although slightly lower than the first model
775 (entropy .89; AIC = 6455.66). Notably, the effect of conscientiousness on transition was significant and
776 negative (-.70, $p < .0001$; odds = .57) and the effect of openness was significant and positive (.96, $p <$
777 .04; odds = 2.61). In agreement with our fourth prediction, it is suggested that personality is involved
778 in cognitive change, with some dimensions impeding and some dimensions facilitating cognitive
779 development (see Model 4, Study 2, Supplementary Material).

780 To examine if the involvement of personality in cognitive change varies with developmental
781 phase, the LTA model above was applied separately on two age groups, 7-11-year and 12-16-year-
782 olds. Some interesting differences between these age groups were observed. First, the probability to
783 transition to a higher state in the younger age group was limited (odds = .14) compared to the older
784 age group (odds = 1.13). This is understandable given that all reasoning domains but arithmetic were
785 principle-based acquisitions which consolidate in adolescence rather than in childhood. Moreover,
786 there were noticeable differences in the factors associated with transition in each age phase. In the
787 younger age group, only working memory (1.23, $p < .001$; odds = 3.34) and plasticity affected
788 transition significantly (1.45, $p < .07$; odds = 4.26). The pattern in the older age group was very similar
789 to the pattern found in the total sample: attention control (2.82, $p < .01$, odds = 16.76), working
790 memory (1.00, $p < .0001$, odds = 2.72), and plasticity (.57, $p < .10$, odds = 1.78) significantly affected
791 transition and stability exerted a negative effect (-.72, $p < .05$, odds = .49) on transition.

792 Therefore, it is suggested that personality is differentially involved in cognitive development. In
793 different developmental cycles different processes relate to change. In rule-based thought, working
794 memory and plasticity catalyze transition to principle-based thought. When already in principle-
795 based thought, stability decelerates change, competing with factors which accelerate change.
796

797 **2.3. Study 3: Cognition, Cognizance, Personality, Emotional Intelligence, and Academic 798 Performance: What is the Go-between?**

799 This study examined a wide range of cognitive, personality, emotional intelligence, and school
800 performance processes from 10 to 20 years of age. Specifically, cognitive abilities included reasoning
801 in several domains (inductive, quantitative, causal, spatial, and social reasoning along a range of
802 developmental levels) and cognizance (self-evaluation of own's own performance and self-
803 representation in the domains above); personality included the Big Five Factors; emotional
804 intelligence was examined both as a trait (self-representations about emotional characteristics) and
805 as an ability (understanding and regulating emotions); finally, information on participants' school
806 performance in Greek and mathematics was obtained. Therefore, this study may show how cognitive,
807 personality, and emotional processes interact from late childhood to early adulthood and how they
808 contribute to academic achievement.

809 Customizing initial predictions to the present study allows testing the following: first, cognition-
810 personality relations would hold, even when likeability effects are removed as possible sources of
811 these effects; second, according to the second and third prediction stated in introduction, given the
812 self-representational nature of personality and emotional intelligence, cognizance would occupy a
813 central role, operating as the bridge between cognition and personality; finally, according to the fifth
814 prediction, academic performance, being the outcome of cognitive, personality, and motivational
815 processes, would depend on all of them.

816 **2.3.1. Method**

817 *Participants*

818 A total of 247 participants were examined. They came from fifth primary school grade (45, 25
819 females; mean age = 10.7 years), first (47, 27 females; mean age = 12.5 years), third (42, 25 females;
820 mean age = 14.9 years) and fifth secondary school grade (33, 22 females; mean age = 16.7), and
821 university (80, 55 females; mean age 20.3 years). These participants had urban residence, living in
822 Nicosia, the capital of Cyprus, and they were representative of the total urban population, dominated
823 by middle-class families.

824 *Tasks*

825 *Cognition.* Cognition was examined by a part of a cognitive development test addressed to
826 several domains [53]. For the present purposes, the following domains were involved: *inductive*
827 (fluid) reasoning was addressed by six Raven-like matrices of varying complexity as specified in
828 Study 1 (levels, ii, iii, and iv); *scientific reasoning* was examined by a combinatorial thinking task
829 (specify all possible combinations in the order of drawing several differently colored balls from a bag)
830 and hypothesis testing by properly mapping hypotheses of varying complexity with relevant
831 patterns experiments; *quantitative reasoning* was examined by algebraic (e.g., specify x if $x = y + z$ and
832 $x + y + z = 30$; when is true that $L + M + N = L + P + N$) and proportional reasoning tasks (e.g., specify
833 how many girls and boys there are in a classroom where we have 30 children and 5 out of 6 are girls);
834 *spatial reasoning* was examined by a paper folding task addressed to mental rotation and two
835 coordination of perspectives tasks (specify the level of liquid in a tilted bottle and the direction of a
836 an object hanging in a track moving at various inclinations); *social reasoning* was examined by two
837 tasks requiring understanding of social intentions and consequences of social actions (Cronbach's
838 alpha = .88).

839 Cognizance was examined by two tests. First, participants self-evaluated their performance on
840 a task from each of the domains included in the cognitive battery above (Raven-like matrices,
841 hypothesis testing, algebraic reasoning, paper folding, and social reasoning). Each of these self-
842 evaluation scores was standardized in relation to the performance score obtained on the respective
843 task to reflect accuracy of self-evaluation (Cronbach's alpha = .54).

844 Second, they answered a self-rating inventory involving three types of self-descriptions: (i)
845 domain-specific abilities related to the domains above (e.g., I can easily decipher how to solve a
846 mathematical problem; I can easily discriminate between evidence related and not related to an event;
847 I easily orient myself in a new city; I can grasp the hidden intentions of others); (ii) *cognizance abilities*
848 related to cognition, emotions, and social behavior (e.g., I know where I am strong and where I am
849 weak; I am able to know my body states (thoughts, emotions); I can easily shift between activities; I
850 can appear calm when I am angry; I can focus on a task even if tired); (iii) *general processing efficiency*
851 (e.g., I am very fast in learning new concepts; I am fast in finding the solution of a problem; I can
852 remember verbatim big chunks of text; I easily keep phone numbers in memory). Scores for self-
853 representation in mathematical, causal-scientific, spatial, and social reasoning, visual and
854 phonological memory, self-control, and ability to know oneself were used in the analyses below
855 (Cronbach's alpha = .90).

856 Personality was examined by the Greek version of the Big Five Personality Inventory. This test
857 addressed two or three facets for each of the Big Five: achievement and order for C; anxiety and self-
858 consciousness for N; extroversion and introversion for E; altruism, sensitivity to others, and
859 agreeableness for A; intellect and openness for O (Cronbach's alpha = .87).

860 Emotional intelligence was examined by two tests. First, trait emotional intelligence was
861 examined by a self-rating inventory (scale 1-5) addressed to *knowledge about emotions* (e.g., I know
862 why my emotions change, I control my emotions, when I am in a good mood I have many new ideas),
863 *sensitivity in recognizing and emitting verbal and non-verbal emotional signals* (e.g., I am aware of the
864 emotional signals I send to others, I recognize someone's emotions on his phase), *style of reacting to*
865 *emotionally loaded events* (When I get high school marks I am not affected, I am not moved by a new
866 nice present; I am indifferent to praise), and *emotional self-regulation* (e.g., I control my emotions)
867 (Cronbach's alpha = .81). This inventory was based on the emotional intelligence scale developed by
868 Schutte [62].

869 Emotional intelligence ability was examined by two tests. The first involved three sections, each
870 addressed to a different aspect of understanding emotions: First, participants rated the degree (1-5)
871 of involvement of several emotions (anger, sadness, joy, disgust, fear, and surprise) in several real-
872 life episodes (obtaining high school marks, failing and winning in sports competitions, impasse in
873 solving a problem, preparing for exams, setting goals for the school year, dealing with a dilemma).
874 The scores given to the most relevant emotion was used in each case (e.g., success-joy, failure-sorrow).
875 Second, this test also examined the ability to specify the emotions involved in a combination of mental
876 states, such as pleasure and expectation, joy and acceptance, sorrow and disappointment, joy and
877 calmness, etc. Nine pairs were given which were scored on a pass-fail basis. The sum of this test was
878 used in the analysis. Third, participants were asked to write three stories about two persons shifting
879 from one emotional state to another (e.g., from being calm and careless to being fearful and anxious;
880 one first feels satisfied, then pleased, then enthused, and finally surprised and proud). Each story was
881 scored on a three-point scale (0, 1, and 2 for irrelevant, partly and fully relevant. The mean score of
882 performance on the three stories was used in the analysis. This test is based on the test originally
883 developed by Mayer and colleagues [63-65].

884 To examine explicit representation of emotions, participants were asked to specify (on 1-5 scale)
885 how much each of 15 descriptions or definitions apply to three emotions (joy, grief, and surprise).
886 The factor score of the first principal component of a factor analysis applied on the ratings for each
887 emotion was used in the analyses below (Cronbach's alpha = .69).

888 School performance was evaluated by school teachers in two subjects: Greek and mathematics.
889 Teachers were asked to rate (1-7 scale) each of their students in several domains: learning complex
890 concepts, learning speed, originality, understanding and using complex concepts, interest, and actual
891 performance in the subject (Cronbach's alpha = .98). School performance measures were not available
892 for university students (N=80).

893 The correlations between measures varied in the fashion of the previous studies. Measures
894 addressed to the same construct correlated moderately to high (circa .3. to .6); correlations across
895 constructs varied between 0 to circa .3 (see correlations in Table A3, in the Appendix).

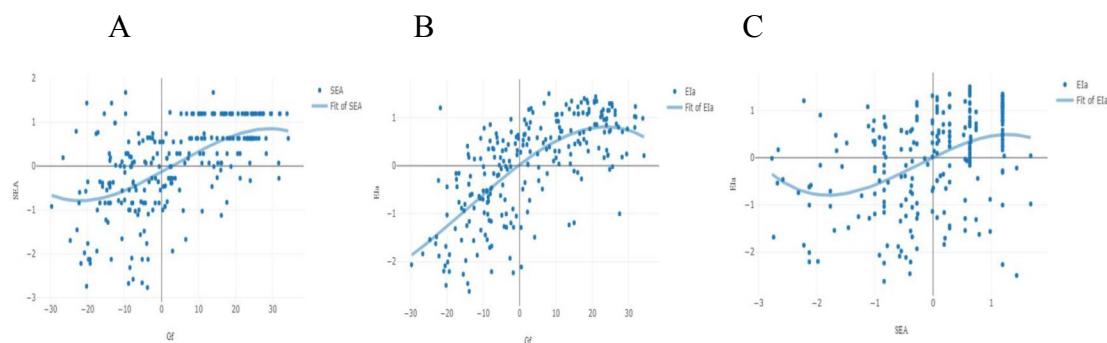
896

897 **2.3.2. Results**898 *Developmental Patterns*

899 Developmental patterns vary as a function of process. Expectedly, all cognitive abilities
 900 developed systematically throughout the age span covered. Individual univariate ANOVAs showed
 901 that the effect of age on (i) cognitive performance, $F(4,242) = 83.70$, $p < .0001$; $\eta^2 = .58$, (ii) self-
 902 evaluation accuracy, $F(4,242) = 31.36$, $p < .0001$; $\eta^2 = .34$, and (iii) understanding emotions was always
 903 strong, $F(4,242) = 36.86$, $p < .0001$; $\eta^2 = .38$, reflecting an almost linear increase in each ability with age.
 904 Obviously, these three aspects of cognitive ability are strongly intertwined in development. Figure 7
 905 illustrates the covariation of the product of age with the factor score of the first principal component
 906 abstracted from each of the three sets of scores.

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911 Figure 7. Relations between Gf and SEA (self-evaluation accuracy) (Panel A, $R^2 = .38$), Gf and Ela
 912 (ability to understand and define emotions) (Panel B, $R^2 = .49$), and SEA and Ela (Panel C, $R^2 = .05$)

913

914 Relations between age and the various traits differed from above. Specifically, self-
 915 representations in cognizance (which is a second-order self-representation) decreased systematically
 916 with age. As a result, the main effect of age was non-significant, $F(4,242) = .65$, $p > .05$; $\eta^2 = .01$, but
 917 the interaction of age with self-representation type was significant, $F(4,242) = 7.14$, $p < .0001$; $\eta^2 = .11$.

918 Similarly, the main effect of age on personality was non-significant, $F(4,242) = 2.09$, $p > .05$; $\eta^2 =$
 919 .03). However, the main effect of personality dimension, $F(4,242) = 71.03$, $p < .0001$; $\eta^2 = .54$, and the
 920 age \times personality interaction were significant, $F(4,242) = 3.61$, $p < .0001$; $\eta^2 = .06$. These effects
 921 reflected two main trends: N was lower than the rest but increased with age; E was high but
 922 decreased; A decreased from 10 to 14 and increased thereafter, topping the rest after 16 years. C
 923 decreased from 10 to 14 and rose thereafter; O decreased systematically from 10 through 16 and rose
 924 from there to 20 years. In emotional intelligence, the main effect of age was again non-significant, F
 925 ($4,242) = 1.21$, $p > .05$; $\eta^2 = .02$; however, processes did differ significantly, $F(2,242) = 323.22$, $p < .0001$;
 926 $\eta^2 = .73$) and they (marginally) differentially related with age, $F(2,242) = 1.73$, $p < .08$; $\eta^2 = .03$. The
 927 cognitive aspects of trait EI (understanding of emotions and regulation of emotional signals wavered
 928 with age but self-representation of emotional stability tended to decrease (Figure 7). In conclusion,
 929 expansion of cognitive ability with age was differentially reflected in various aspects of self-
 930 representation and personality with some varying with states of ability and some becoming stricter
 931 or more conservative. The models to be presented below will shed light on these relations.

932

Relations between Processes

933 The multiplicity of measures used in this study provides a rich basis for studying the relations
 934 between the various processes measured. Thus, two different approaches were used. First,

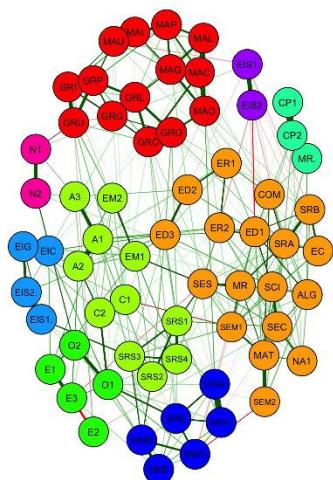
935 Exploratory Graph Analysis was used to map the organization of processes. Second, structural
 936 equation modeling was used to specify their relations.

937 *Exploratory Graph Analysis (EGA).* Exploratory Graph Analysis is part of a new area called
 938 network psychometrics (see [66]), which focuses on the estimation of undirected network models (i.e.
 939 Markov Random Fields [67]) to psychological datasets. EGA can show if measures form nodes that
 940 connect with each other into clusters standing for underlying latent variables. Golino and Demetriou
 941 [68] showed that EGA is more accurate than other methods, including confirmatory factor analysis,
 942 to reveal the dimensions underlying performance on various cognitive test batteries under a variety
 943 of test and sample conditions. They suggested that EGA may be the method of choice to uncover
 944 underlying dimensions of behavior or ability in fields of study where clear theory specifying
 945 constructs and their relations is not yet available. Structural equation methods may then be used to
 946 validate EGA findings and more exactly specify the direction of relations between constructs.

947 It may be noted here that each of the Big Five Factors emerged as a separate cluster when only
 948 the scores obtained from the Big Five Inventory were used in the analysis. Figure 8A shows the best-
 949 fitting EGA model, χ^2 (1791) = 4074.84, CFI=.98, RMSEA = .072, applied on the full set of scores
 950 obtained in this study. Clusters are shown in different colors. It may be seen that there are three very
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954 Figure 8. Network of abilities and processes as abstracted by Exploratory Graph Analysis (Panel A)
 955 and hierarchical organization of clusters as abstracted by Hierarchical Exploratory Graph Analysis.
 956 Note: Clusters represent general academic performance measures (1: GAP), general cognitive ability
 957 (2: GCA), general self-representation of social competence cluster (3: GSC), plasticity of personality
 958 (4: PLA), spatial reasoning (5: SPA), knowing one's own emotions (6: E1c), self-representation of
 959 mental efficiency (7: GCC), emotional stability (8: E1s), and neuroticism (9: N) from the Big Five,
 960 respectively.

961

962 broad clusters and several narrower ones. The first broad cluster included all academic performance
 963 measures (GAP). The second was a cognition cluster including most of the cognitive and all self-
 964 evaluation accuracy (SEA) and the ability to understand emotions scores (E1a). Therefore, this is a
 965 very powerful cluster standing for general cognitive ability (GCA). Notably, there was also a very
 966 broad self-representation of social competence cluster (GSC) which included self-representations of
 967 causal and social reasoning A and C from the Big Five, and handling exchange of emotional
 968 information from E1t. Plasticity of personality, including all E and O measures, emerged as a separate
 969 cluster (PLA). Clusters 5, 6, 8, and 9 are specific, standing for spatial reasoning (5: SPA), knowing
 970 one's own emotions (6: E1c), self-representation of mental efficiency (7: GCC), emotional stability (8:
 971 E1s), and neuroticism (9: N) from the Big Five, respectively.

972 The hierarchical organization of these factors was explored by Hierarchical Exploratory Graph
973 Analysis (HEGA). HEGA uses Hierarchical Random Graphs to specify the hierarchical organization
974 of the various latent factors. Hierarchical random graphs were developed by Clauset, Moore and
975 Newman [69] as a probabilistic technique to detect hierarchies in network structures. It works by
976 combining a maximum-likelihood approach with a Monte Carlo sampling algorithm to generate
977 artificial networks with a given hierarchical structure. By using this approach, the space with all
978 possible dendrograms whose probability is proportional to the likelihood that they generated the
979 observed data is analyzed. A consensus dendrogram is obtained by using a MCMC algorithm in an
980 estimated hierarchical random graph, containing only the dendrogram features that appear in the
981 majority of the sampled models. Hierarchical random graphs can be combined with Exploratory
982 Graph Analysis to investigate how different latent factors are organized in a hierarchy.

983 In this paper we adopted a three-step approach. First, data was iteratively analyzed by EGA
984 until all factors related to at least two items and the resulting structure was verified by CFA to fit the
985 data well. Second, based on this structure, a factor score for each factor was computed for all
986 participants; these factor scores were again fed in EGA to estimate a network of the relationships
987 between the variables. Finally, the network obtained in the previous step was used as input to the
988 hierarchical random graphs technique, available in the *igrpah* package, until a consensus hierarchical
989 network was obtained. This network is derived by weighting the hierarchical features by their
990 likelihood based on a process akin to Bayesian model averaging. This is dendrogram model that may
991 most likely generate the observed data [70].

992 In line with structural equation modeling, the HEGA approach can be used to identify structural
993 relations in multivariate data. However, while in the later the relationships need to be specified by
994 the researcher, in the former this is done automatically. Also, the HEGA approach is used to see how
995 variables are connected in a hierarchical organization only. In SEM, the structure can have any form,
996 not just hierarchical. Thus, both techniques can be seen as complimentary to each other, being HEGA
997 an exploratory approach and SEM a confirmatory one.

998 This organization is shown in Figure 8B: it may be seen that the nine factors above are organized
999 in two major systems, one capturing the procedural cognitive aspects of the mind (M_c) and the other
1000 the self-representational, social and emotional aspects of the mind (M_s). The M_c system is grounded
1001 on general cognitive ability and academic performance, which integrate into a common block
1002 standing for thinking and learning (G7); this intertwines with the α -factor, plasticity of personality,
1003 to form a higher level, flexibility in cognition and learning (G2); finally, flexible cognition and
1004 learning integrate spatial cognition into a higher level (G5). M_s is grounded on two branches: the first
1005 (G8) involves self-representation of general social (GSC) and cognitive competence (GCC); the second
1006 (G4) involves N from the Big Five and EIC; these two branches unite into a higher level (G3) which,
1007 together with M_c (G5) form a level where the two systems merge into a higher level common (G6).
1008 This, together with emotional stability merge at the top in what Wechsler would call the personality
1009 as whole gP.

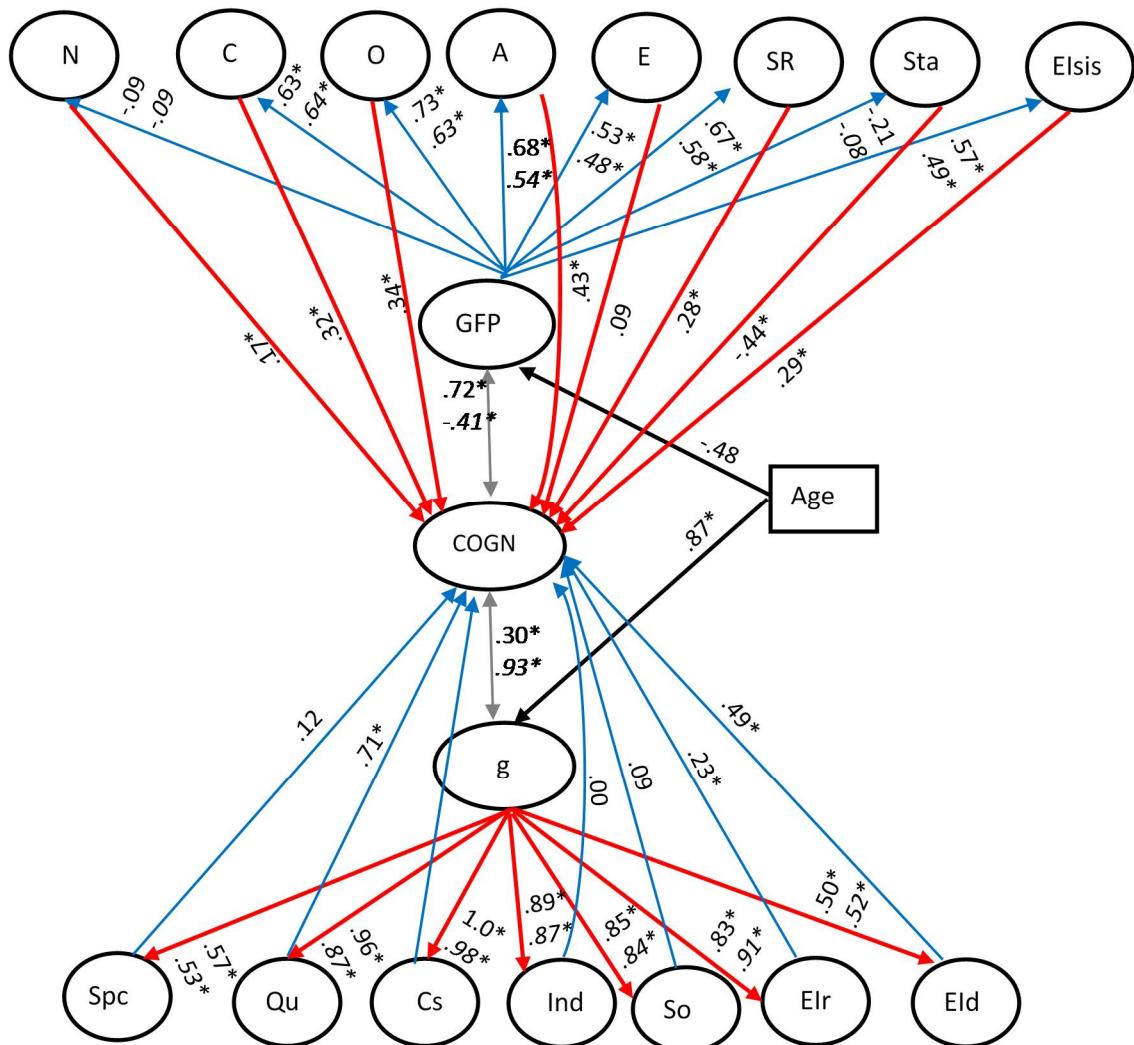
1010 *Testing the effect of likeability on structural relations.* The findings above suggested that cognition,
1011 personality, emotional intelligence, and academic performance are related. To decompose their
1012 relations at several levels, three classes of models were tested. The first class of models examined if
1013 these relations are shaped by likeability rather than their sharing of common processes [29]. In sake
1014 of this aim a likeability scale was formed. This scale included 14 items explicitly probing individuals
1015 to specify how they score on several positive characteristics in cognition (e.g., I have a strong memory,
1016 I am fast in understanding), personality (e.g., I am organized, I am bright, I am honest), and emotional
1017 intelligence (e.g., I know what others feel by just looking at them). The reliability of this scale was
1018 high (Cronbach's alpha = .74). Notably, the correlations between this scale and age (-.35) and gf (-.32)
1019 were similar in magnitude and direction to the corresponding correlations of Eysenck's L scale
1020 observed in Study 1, suggesting that likeability decreases with age or cognitive ability.

1021 To examine the possible effect of this scale on the relations between factors, a model was built
1022 which included three cognitive factors (Gf, understanding, and specifying emotions), three
1023 cognizance factors (self-evaluation accuracy, self-representation in specific domains, and self-

1024 representation of self-knowing ability), the Big Five Factors, and three traits of emotional intelligence
1025 (i.e., self-awareness about emotions, emotional stability, and recognition and management of
1026 emotional signals). The three cognitive factors were related to one general cognition factor (g); the
1027 three cognizance factors were related to another (COGN); C, A, and N were related to one factor (α -
1028 stability) and O and E to another (β -plasticity); the three EI trait factors were related to another factor;
1029 these last three factors were related to a common higher-order personality factor (GFP). At a first test
1030 of the model, the correlations between these three higher-order factors (g, COGN and GFP) were
1031 constrained to be 0, (χ^2 (1020) = 2267.32, CFI= .991, RMSEA = .071, model AIC = 227.32. At a
1032 next test, these correlations were left free to be estimated, (χ^2 (1017) = 2161.07, CFI= .992, p >.001,
1033 RMSEA = .068, model AIC = 127.08. The difference in the fit of the two models was highly significant
1034 ($\Delta\chi^2$ (3) = 106.25, p < .001), reflecting the fact that all three correlations were significant ($R_{g,COGN}$ = .53;
1035 $R_{g,GFP}$ = .24; $R_{COGN,GFP}$ = .64). Finally, this last model was tested after partialling out the effect of the
1036 likeability scale from the relations of each cognizance, personality, and emotional intelligence
1037 measure with the factor it was related to, (χ^2 (1030) = 2098.11, CFI= .992, p >.001, RMSEA = .065, model
1038 AIC = 227.32. Although still good, the fit of this model was not better than the second model above.
1039 This reflected the fact that the correlations between the three higher order factors were still significant
1040 ($R_{g,COGN}$ = .67; $R_{g,GFP}$ = .42; $R_{COGN,GFP}$ = .62); noticeably, the correlation between g and the GFP increased
1041 rather than dropped in spite of partialling likeability out. Obviously, the relations between these three
1042 factors are genuine rather than an artefact of likeability (Study 3, Model 1, Supplementary Material).

1043 *Specifying cognizance mediation.* The second class of models tested the assumed mediation role of
1044 cognizance. Specifically, models in this class tested how, if at all, cognizance mediates between
1045 cognitive and personality processes bottom-up and top-down, carrying experiences from mental
1046 processing to personality and emotional dispositions and vice-versa. These models included the
1047 following first-order cognitive factors: spatial, quantitative, causal, inductive, and social reasoning
1048 defined by performance on the tasks described above (see method); two factors capturing emotional
1049 intelligence as an ability (i.e., association of different emotions with corresponding real-life situation
1050 and specification of characteristics of different emotions); all seven factors were regressed on a
1051 second-order Gf factor. Also, there were three factors for cognizance (i.e., SEA, related to self-
1052 evaluation accuracy; SR_d, related to self-representation about these domains; SR_{sk} related to self-
1053 representation of self-knowing ability, which were regressed on a second-order cognizance factor
1054 (COGN). Finally, there were eight factors for personality and emotional intelligence traits (i.e., one
1055 factor for each of the Big Five factors, associated with the facet scores included in each factor—see
1056 method—and self-awareness about emotions, emotional stability, and recognition and management
1057 of emotional signals); these eight factors were regressed on a common second-order factor standing
1058 for GFP. To examine the mediation role of cognizance, in the bottom-up model, the COGN factor was
1059 regressed on Gf and the residuals of each of the seven domain-specific cognitive factors; the GFP was
1060 regressed on COGN. Thus, this model captures how cognizance mediates the effects of general
1061 cognitive ability and the specific processes represented by each domain-specific factor to the
1062 personality and emotional intelligence factor. The fit of this bottom-up model was very good, χ^2
1063 (1251) = 2327.93, CFI= .997, p >.001, RMSEA = .060, model AIC = -174.07 (Study 3, Model 2,
1064 Supplementary Material).. In the top-down model, the COGN factor was regressed on GFP and the
1065 residuals of each of the personality and the emotional intelligence trait factors; the Gf factor was
1066 regressed on the COGN factor; thus, this model captures how cognizance mediates the possible
1067 effects of GFP and each of the specific personality and emotional intelligence traits on cognitive
1068 ability. Although also good, the fit of this top-down model was weaker than the fit of the bottom-up
1069 model, χ^2 (1252) = 2506.55, CFI= .996, p >.001, RMSEA = .064, model AIC = 2.47. Two further models
1070 were tested: one assumed that Gf is the mediator between COGN and personality, χ^2 (1254) = 2367.07,
1071 CFI= .997, p >.001, RMSEA = .061, model AIC = -140.93; the other assumed that GFP is the mediator
1072 between cognition and cognizance, χ^2 (1254) = 2564.70, CFI= .997, p >.001, RMSEA = .066, model AIC
1073 = 56.70 (Study 3, Model 3, Supplementary Material).. Both models were weaker than the bottom-up
1074 model, although the first of them fit better than the top-down model. Figure 9 shows the bottom-up
1075 model; the values of the top-down model are also shown for comparison purposes.

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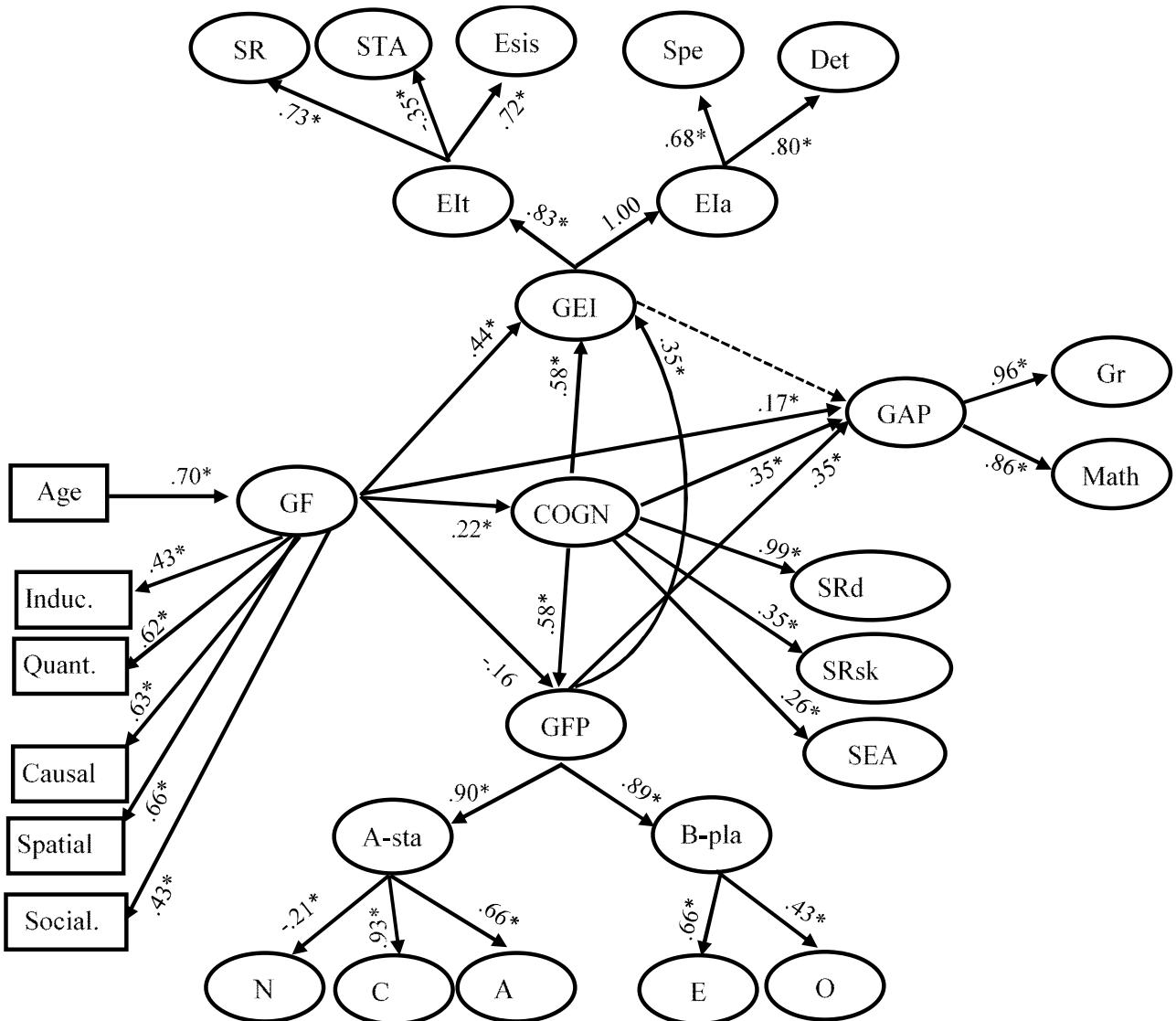
Figure 9. The bottom-up (blue arrows) and top-down (red arrows) mediation models showing how cognizance mediates between cognition and personality.

1082 Note. The first and second number pair come from the bottom-up and the top-down model, respectively.
1083 The grey arrows connecting g, cognizance (COGN), and the GFP should be read as either pointing upwards (the
1084 bottom-up model, first number of each pair) or downwards (the top-down model, second number of each pair).
1085 Symbols Spc, Qu, Cs, and Ind stand for spatial, quantitative, causal, and inductive reasoning; symbols EIr and
1086 Eid stand for the ability to understand, and specify emotions, respectively; the symbols N, C, O, A, and E stand
1087 for the Big Five Factors; the symbols SR, Sta, and Elsis stand for self-awareness about emotions, emotional
1088 stability, and recognition and management of emotional signals, respectively. Asterisks indicate significant
1089 relations (see complete models in Supplementary Material Study 3, Models 2 and 3).

1091 Altogether, these models suggest that there is a strong flow of influences running across
1092 cognitive and personality systems. The supremacy of the cognitive over the personality mediation
1093 models suggests that cognitive mechanisms operate as stronger relay centers than personality
1094 mechanisms. If a direction of the flow of influences would have to be chosen, the supremacy of the
1095 bottom up cognizance mediation model indicates that experiences of mental processing project onto
1096 cognizance which carries them forward to personality and emotional functioning. It may be seen in
1097 Figure 9 that, in addition to Gf (.30), quantitative reasoning (.71) and the ability to specify different
1098 emotions (.49) exerted strong influences on cognizance. In turn, cognizance exerted strong effects on

1099 GFP (.72) and also four of the Big Five (C, O, A, E) and two of EI traits (SR, EI_{sis}) (all > .5). In the top-
1100 down model, all but one of the eight Big Five and EI traits exerted significant effects on cognizance
1101 with C, A, and emotional stability to be in the lead. Notably, the effect of the GFP on COGN was
1102 negative (-.41), reflecting the already substantiated involvement of likeability in the relations between
1103 personality and self-representation and self-evaluation.

1104 *Accounting for academic performance.* The third class of models aimed to specify how academic
1105 performance relates to the various processes studied. The best fitting model is shown in Figure 10.
1106 This model involved the following first-order factors: Gf, related to mean performance on each of the
1107 cognitive domains; the three cognizance factors above (SEA, SR_d, and SR_{sk}) were related to a second-
1108 order factor standing for cognizance (COGN). Three of the Big Five factors, N, C, and A were related
1109 to the α -factor, stability, and E and O were related to the β -factor, plasticity of personality; in turn,
1110 these two second-order factors were regressed on a third-order factor standing for the GFP. The three
1111 factors capturing emotional intelligence traits and two factors capturing emotional intelligence as an
1112 ability were regressed on their corresponding second-order factors (EI_t and EI_a); these factors were
1113 regressed on the general emotional intelligence factor (GEI). Finally, academic performance was
1114 related to the means of performance in Greek and mathematics (GAP). The following structural
1115 relations were built into the model: Gf was regressed on age, COGN was regressed on Gf, GFP was
1116 regressed on Gf and the residual of COGN; GEI was regressed on Gf and the residuals of COGN and
1117 GFP; GAP was regressed on Gf and the residuals of COGN, GFP, and GFI factor. This model
1118 implements the assumption suggested by the bottom-up mediation model presented above that
1119 cognizance mediates between cognitive ability, on the one hand, and personality and emotional
1120 intelligence, on the other hand. Using only the Gf factor as such in all relations and the residuals of
1121 the other factors assumes that each factor, at a specific level in the hierarchy, involves a fundamental
1122 component of mental processing and, additionally, other processes specific to the levels intervening
1123 between general cognitive ability and the specific factor concerned. Residualizing these intervening
1124 factors purifies them, technically speaking, from components specific to the other factors already
1125 used. The fit of this model was very good, χ^2 (1103) = 1701.49, $p > .001$, CFI = .994, RMSEA = .058.



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1130 Figure 10. The second model of cognitive abilities, personality, emotional intelligence and school
1131 performance. $\chi^2(1103)=1701.49$, $p<.05$, $CFI=.994$, $RMSEA=.058$ (.052-.06), $AIC=-404.51$.

1132 Note. Symbols are specified in Figure 9. Additionally, the symbols Gr and Math stand for school performance
1133 in Greek and mathematics, respectively; GAP stands for general academic performance; the symbols SRd, SRsk
1134 and SEA stand for self-representation in specific domains, self-knowledge and self-regulation, and self-
1135 evaluation, respectively; the symbols Ela and Elt stand for ability and trait emotional intelligence, respectively;
1136 the symbols A-sta and B-PLA stand for the stability plasticity factors of personality, respectively (see complete model in
1137 Supplementary Material Study 3, Model4).

1138

1139 This model is complementary to the network and the hierarchical models presented above in
1140 that it highlights the (statistically) causal relations between the various clusters. Noticeably,
1141 cognizance was a central hub in the system: it was affected by Gf (.22) but it did affect the GFP (.58),
1142 GEI (.58) and academic performance (.35); Gf also significantly affected GEI (.44), academic
1143 performance (.17) and, non-significantly, GFP (-.17); the negative direction of this relation reflected
1144 the influence of A (see below); academic performance was also affected, equally, by both GFP (.35)
1145 and GEI (.35). To examined possible differences in the effects of the α - and the β -factor of personality
1146 on GAP, the GFP was abolished and GAP was regressed on both personality factors. Notably, the
1147 effect of plasticity, the β -factor (.81) was much higher than the effect of stability, the α -factor (.42).

1148 One might note that the relation between Gf and GAP was lower than is often reported in the
1149 literature. Indeed, in the present data this relation increased to .40 in a model where only the Gf and
1150 the school performance factors were involved; further, it rose to .56 when Gf and the cognizance
1151 factors were associated to a single GCA factor. Regressing cognizance on Gf (.60) and GAP on Gf (.18)
1152 and the residual of cognizance (.63) showed that the later relates more strongly with GAP than the
1153 former. Along the same line, a model involving only the personality and the academic performance
1154 factors indicated that personality effects on school performance, in addition to the GFP as such (.26),
1155 originated from C (.33), A (-.19) and O (.15).

1156 This model was tested in a two-group analysis including participants from 10 to 14 years in one
1157 group and participants from 16 to 20 years in another group. All measurement-factor relations were
1158 constrained to be equal across the two groups; the factor-factor relations were left free to vary across
1159 the groups to examine if relations between factors change with age. The fit of this model was good,
1160 χ^2 (2003) = 3231.85, CFI = .997, $p > .001$, RMSEA = .071, model AIC = -774.35. Of the various relations,
1161 only three noticeable differences between these two age groups emerged: on the one hand, the effect
1162 of Gf on the GEI in the younger group (.33) was significantly higher ($z = 3.22$, $p < .01$) than in the older
1163 group (-.10); on the other hand, the effect of Gf on cognizance (.19 vs. .29 for the younger and older
1164 participants, respectively; $z = 1.06$, $p > .05$) and the effect of cognizance on the GFP (.55 vs. .93; $z =$
1165 2.41, $p < .01$) were larger in the older group. This pattern of age differences indicates that early in
1166 adolescence, a period of transition from rule- to principle-based thought, cognitive changes influence
1167 EI; later, when cognitive ability gets stabilized and cognizance becomes sharper and more accurate,
1168 self-representations and self-characterizations in personality also become more accurate, and some-
1169 times stricter than early in development. As discussed below, these relations are generally in line
1170 with predictions.

1171 In conclusion, the results of this study suggested, in line with predictions, that the relations
1172 between general factors of cognition, personality, and emotional are present even when likeability is
1173 statistically removed. Cognizance was a central core underlying these relations. Finally, school
1174 performance was affected by both, cognitive and cognizance factors, but also personality factors,
1175 conscientiousness in particular.

1176

1177 3. Conclusions

1178 The implications of our findings may be better evaluated if some unique characteristics of the
1179 three studies are highlighted. Altogether, the three studies included (1) a wide age range, from 4 to
1180 20 years, which is crucial for cognitive and personality development; (2) a wide range of cognitive
1181 (information processing, executive control, reasoning, and self-awareness) and personality processes
1182 (Eysenck's factors, the Big Five Factors, and emotional intelligence), uncovering relations that would
1183 not be observed otherwise; (3) three different countries (Greece, Croatia, and Cyprus), providing
1184 cross-cultural validity to the findings; (4) longitudinal measures highlighting developmental
1185 relations within individuals rather than different age cohorts.

1186 *Structure.* Altogether, the three studies suggest, in line with the first prediction, that cognition
1187 and personality are distinct but related at several levels. At a basic level, the network and hierarchical
1188 models in Study 3 suggested that some processes in each system interlock it with the other system:
1189 mental plasticity (O in particular) is personality's envoy in cognition; self-concept is cognition's
1190 envoy in personality. At a higher level, all three studies showed that the relation between g and the
1191 GFP was significantly and substantively different from 0 in the models. This finding suggested that mental
1192 power is projected into personality, regardless of age or social likeability. We trust that the great
1193 scholars mentioned in the introduction, Allport, Wechsler, and Jensen, would be pleased to see that
1194 cognition (g) and personality (GFP) merge into gP. It is reminded that the general factor in each
1195 discipline, g in intelligence and GFP in personality, is disputed within each field as a technical artefact
1196 of measurement. The present studies suggest a Godelian restoration of both in the context of a higher-
1197 order factor, gP, that captures the substance of both: general processing, representational, and
1198 inferential efficiency (cognition) that is expressed into a person's dispositional efficiency in handling
1199 his or her interactions with the world (personality). Cognizance is the central mechanism shared by

1200 the two general factors. This mechanism translates experiences from cognitive and social social
1201 interactions with the world into values of self-worth, confidence, and self-efficacy, rendering them
1202 complementary manifestations of these two aspects of efficiency. These values set the range of
1203 variation across personality dimensions, such as each of the Big Five Factors or broader dimensions,
1204 such as stability and plasticity.

1205 These findings are relevant to the dispute about the existence and nature of GFP. Some authors
1206 dispute its very existence, claiming that it reflects social desirability running through self-ratings [71]
1207 or measures that carry same-factor components across unrelated factors [72] rather than any other
1208 actual psychological mechanism. Others suggest that its presence varies depending upon the level of
1209 measures used to specify relations. For instance, it emerges in self-ratings but not in multirater nested
1210 data [73] and its strength increases with increasing hierarchical level of the dimensions involved [74].
1211 The studies presented here suggest a comprehensive interpretation of these seemingly divergent
1212 patterns of evidence. For one thing, the GFP survived even when the effect of desirability was
1213 partialled out (Study 3). For another, when present, desirability is an indicator of cognizance
1214 processes shared by cognition and personality rather than as noise to be removed. These processes
1215 rescale self-ratings towards the stricter end of a personal self-evaluation scale along with intellectual
1216 growth; hence the ubiquitous negative relation between indexes of intellectual growth and various
1217 indexes of desirability (Study 1). Naturally, in line with the findings above [74], GFP strengthens with
1218 increasing hierarchical level of the dimensions involved because cognizance processes are by
1219 definition second- or higher-order processes: i.e., they apply on task-specific cognitive or personality
1220 processes, although they may emerge from processes where task-specific processes and self-
1221 regulation processes merge in the same task, as in attention control processes (Study 2).

1222 The so called emotional intelligence was not an autonomous dimension. Its cognitive
1223 components were absorbed by the inferential system and its social components aligned with
1224 personality factors standing for dispositions underlying social interaction. These findings confirm
1225 recent research showing that emotional intelligence is probably synonymous with the processes
1226 captured by the GFP [75]. However, Study 3 suggested that cognitive processes activated in dealing
1227 with emotions do have a role in cognition-personality relations that goes beyond cognition: they
1228 contribute special experiences in the formation of cognizance which are projected in personality.

1229 *Development.* Relations between cognition and personality vary with development, depending
1230 on the representational possibilities and the behavioral and social needs of successive developmental
1231 phases. According to our second prediction, self-representations improve with age and liaise between
1232 cognition and personality with increasing accuracy and refinement. Study 3 showed that the accuracy
1233 of self-evaluations of actual cognitive performance improved systematically from 9 to 20 years along
1234 with improvements in cognitive ability. In fact, alignment of all aspects of self-representation with
1235 each other and cognitive ability tightened with age, suggesting that cognitive processing, be it object-
1236 or socially-emotionally oriented, becomes inseparable from the various aspects of cognizance.

1237 According to the third prediction, cognizance would function as the central hub between all
1238 other functions involved. This was indeed the case, as suggested by Study 3. In fact, this role
1239 expressed itself in several seemingly unrelated trends captured by the other studies. Specifically, at
1240 a first glance, it would be paradoxical that Eysenck's likeability would be such a powerful
1241 developmental factor, as found by Study 1: its decrease with age was an accurate index of cognitive
1242 development. Obviously, L stands up, among the other personality factors, as a strong self-
1243 representational agent: with development it scales down to reflect increasing accuracy in self-
1244 representation and self-evaluation. Obviously, decrease here does not imply loss of ability; it implies
1245 adjustments in self-representations of both cognitive and social characteristics, along with cognitive
1246 improvement. These seemingly contrasting trends give a developmental dimension to Socrates
1247 epistemic insight: "The only thing I know is that I know nothing" is not just an attainment of
1248 philosophical minds. It is a developmental construction inherent in cognitive change which is
1249 gradually integrated into the development of personality. Additionally, these trends indicate that
1250 high L scores, when persisting in adulthood, may be a frozen remnant of developmental processes
1251 that are highly active in late childhood. A developmental interpretation of this remnant might invoke

1252 the developmental equivalent of average IQ of 100 characterizing the majority of adults. According
1253 to this interpretation, mean IQ corresponds to late rule-based thought [76]. Thus, high levels of L in
1254 the general population express the general population's modal cognitive developmental level.

1255 According to the fourth prediction, some aspects of personality have a privileged relation with
1256 various aspects of cognition. This was a standard finding across all three studies. On the one hand,
1257 plasticity, the β -factor, proved to be an integral component of the mind. In Study 2, the β -factor as
1258 such, O in particular, contributed to the likelihood of longitudinal change, especially in adolescence.
1259 Notably, the inverse relation was also observed. That is, cognitive change did raise the likelihood for
1260 change in personality. Study 2 showed that plasticity did carry some deep-rooted trends associated
1261 with attentional control, which at surface may not seem related to a top-tier level of personality
1262 functioning, such as the β -factor. The relations uncovered by the model shown in Figure 6 (Study 2)
1263 suggested that an advantage in processing efficiency at a given time translated into increased
1264 plasticity one year later. In Study 3, the β -factor aligned with the cognitive rather than with the
1265 personality system. On the other hand, some aspects of the α -factor, C in particular, negatively related
1266 to the likelihood of cognitive developmental change (Study 2). In contrast, in line with the expected
1267 paradox, C did relate positively with academic performance. One might assume that this apparent
1268 paradox simply reflects the double role of C in actual functioning in real life. The first: individuals
1269 high in C are slower in cognitive change perhaps settling lower at their final cognitive level because
1270 they are conservative in facing challenges inducing change; this is the advantage of individuals high
1271 in O and E. It is interesting that this effect was observed at the age period related to the acquisition
1272 of principle-based thought rather than earlier. Thus, one might assume that C interferes with
1273 cognitive change related to the acquisition of a more open, suppositional style of thought rather than
1274 the more systematic rule-based thought of childhood. The second: this very seeming weakness
1275 provides an advantage in realms of activity where self-discipline, order, and systematicity pay off in
1276 the long run. Obviously, school learning and academic performance is one such realm, par excellence.
1277 More research is needed to map and more precisely specify these effects.

1278 The patterns above suggest a more balanced picture of cognition-personality relations than the
1279 relations suggested by the investment model summarized in the introduction. The investment model
1280 assumes that cognitive ability is a capital that may or may not be profitably invested by personality
1281 investing agencies [49-51]. This economic interpretation of the human mind assumes a segregation
1282 between cognition and personality that does not do justice to its integrity which drives the developing
1283 individual to establish an optimally balanced relation with the environment. Our findings suggest
1284 that cognitive development is an adaptive constructive process that includes a mental
1285 (representational and inferential), an interactive (dealing with the physical, the cultural, and social
1286 environment), and a motivational component (the will to pursue specific actions given their relative
1287 demand on mental resources and their relative value for ongoing interaction needs). All three
1288 components are inter-dependent and changes in any one of them would cause changes in the others,
1289 expanding the adaptive possibilities of the individual. Under this model, developmental changes in
1290 mental processes would cause changes in their expression in interactive and motivational tendencies
1291 as much as the results of interactive and motivational engagement with the environment may
1292 feedback to mental activities causing their further development.

1293 The loops of causal interactions between these three components may vary in development,
1294 depending upon the cognizance possibilities of successive developmental cycles. For instance, the
1295 relatively superficial self-monitoring possibilities of the realistic representations cycle would not
1296 generate the necessary representational material that would allow the preschool child to deploy a
1297 representational change strategy in response to negative social or action feedback or a behavioural or
1298 motivational change strategy in response to the evaluation of interactive possibilities associated with
1299 alternative representations of a situation. In childhood, the consolidation of rule-based thought and
1300 the turn of cognizance from perceptual to mental and personality processes enable children to more
1301 systematically conduct themselves in a world of obligations and expectations, where different
1302 contexts demand different behaviors. At this period of life, however, the nascent self-monitoring and
1303 self-representation possibilities still lack an overall evaluation system that would allow to place

1304 values on different experiences and actions. Hence, the inflation of self-value judgements, reflecting
1305 this developmentally nascent sense of mental and behavioral power. Later in adolescence, emergence
1306 of principle-based thought and increasing resolution of self-knowing causes a more conservative
1307 approach to self-representation which integrates epistemic recognition of the limits of one's own
1308 mental power with the limitations of one's positive characteristics. This allows relatively fluid multi-
1309 directional interactions between the three components in adolescence, for those individuals who do
1310 enter principle-based thought.

1311 *Limitations.* The findings of the three studies suggest several limitations in our understanding of
1312 cognition-personality relations in development. First, self-ratings expressing self-representations,
1313 which is typical in personality research, may be relatively valid with late rule-based thought or later.
1314 Self-ratings require (i) relatively explicit self-representations that may be subjectively
1315 dimensionalized and (ii) mapping these subjective dimensions onto a scale varying along a certain
1316 metric specified by the researcher. Both abilities are not present before late rule-based thought. In
1317 fact, it is only with principle-based thought, in adolescence, that persons possess an elaborate self-
1318 evaluation ability and a refined self-concept that they may use to specify their cognitive, emotional,
1319 personality, and behavioral characteristics [77]. Therefore, change in the state of personality
1320 dimensions and in the relations between cognition and personality from childhood to adulthood
1321 observed by research [6, 10, 43-44] may reflect changes in the accuracy of self-monitoring and self-
1322 evaluation as much as actual changes in the relations between mental and personality processes.
1323 Further research is needed that would compare cognition-personality relations as emerging from
1324 actual social interactions with relations emerging from self-ratings as it was done here.

1325 A second limitation is concerned with the precise cognition-personality relations at successive
1326 developmental cycles. For instance, what are the ideal values of each of the Big Five at each cognitive
1327 developmental phase or cycle? Are the Big Five Factors relevant for the cycles of episodic or realistic
1328 representations? It might be the case that at these early periods of life an ideal mastery of executive
1329 processes with control of emotion are more relevant to successful development than dispositions
1330 such as agreeableness or openness [5, 7]. What level of openness or conscientiousness goes with rule-
1331 based or principle-based thought? It might be the case that rule-based thought goes well with C
1332 whereas principle-based thought goes well with O. Study 2 suggested that this is possible. It is noted
1333 here that we may not fully understand how cognition-personality relations vary later in life unless
1334 we understand how they relate early in life when changes occur in both. For instance, recent research
1335 suggested that O continues to associate with cognitive ability in old age and that, with
1336 conscientiousness, slow cognitive decline [78, 79]. The present studies provided only limited
1337 information relevant to these questions because the methods used for mapping personality
1338 dispositions were designed for adults; therefore, they are minimally sensitive to developmental
1339 variations. We hope, however, that raising these questions will direct future research to generate
1340 better answers than we obtained here.

1341 6. Patents

1342 This section is not mandatory, but may be added if there are patents resulting from the work
1343 reported in this manuscript.

1344 **Supplementary Materials:** The following are available online at www.mdpi.com/xxx/s1, Figure S1: title, Table
1345 S1: title, Video S1: title.

1346 **Author Contributions:** Conceptualization, statistical analysis, and writing A.D.; Design and execution of Study
1347 1 A.D. and S.K.; Design and execution of Study 2 and editing M.Z.; Design and execution of Study 3 A.D. and
1348 M.A.; Modeling, visualization, and editing G.S.; Modeling by EGA and HEGA of Study 3 and related writing
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1354 **Conflicts of Interest:** The authors declare no conflict of interest.

1355 **Appendix A**

1356 The appendix is an optional section that can contain details and data supplemental to the main
1357 text. For example, explanations of experimental details that would disrupt the flow of the main text,
1358 but nonetheless remain crucial to understanding and reproducing the research shown; figures of
1359 replicates for experiments of which representative data is shown in the main text can be added here
1360 if brief, or as Supplementary data. Mathematical proofs of results not central to the paper can be
1361 added as an appendix.

1362

1363 **Appendix B**

1364 All appendix sections must be cited in the main text. In the appendixes, Figures, Tables, etc.
1365 should be labeled starting with 'A', e.g., Figure A1, Figure A2, etc.

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