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Effect of Smartphone Use on Mental Prosperity and Scholastic Execution

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Abstract

The present developmental study aimed to examine the influence of individual differences in three prominent facets of temperament (i.e. approach motivation, impulsivity, and sensation seeking) on fluid intelligence beyond age in adolescent age ranges. We were hereby interested in both their unique contributions as well as their shared influence on fluid intelligence. Furthermore, we aimed to investigate if the relationship between these temperamental facets and fluid intelligence would vary as a function of age. Using hierarchical multiple linear regression analysis, we found in a cross-sectional sample of N=188 adolescents ranging from 9 to 18 years of age: (1) a significant positive relationship between age and fluid intelligence, suggesting a linear increase of fluid intelligence from childhood to adolescence; (2) an incremental impact of temperament on fluid intelligence beyond age. Importantly, this temperamental influence on fluid intelligence seemed to be mostly driven by the impulsivity facet, and not by approach motivation or sensation seeking; (3) an unexpected age-invariance of the relationship between temperament and fluid intelligence; and (4) no age-related changes within approach motivation or impulsivity, while a linear increase of sensation seeking from childhood to late adolescence. These findings may help specify the tripartite relationship between age, temperament, and cognition in adolescence.

Introduction

According to the two-component model of intelligence that describes differential developmental trajectories of intellectual abilities across the lifespan [1,2]. Intellectual abilities can be separated into 'crystallized' and 'fluid abilities' [3] 'Crystallized' intelligence is primarily a culturally mediated domain of intelligent behavior, including verbal- or wisdom-related knowledge, while 'fluid' intelligence is a biologically determined domain of intelligent behavior, encompassing basic mechanisms like perceptual speed, attention, spatial orientation, or reasoning. In the present study, we focus on the fluid component of intelligence due to its particular relevance for the development in childhood and adolescence: Fluid cognitive abilities are strongly positively correlated with age across childhood and adolescence [4-6] given that they mature earlier, thus building the basis for the culturally mediated bodies of knowledge [7,8] and that they have been linked specifically to the achievements in core developmental tasks of the adolescent period, such as school and first academic success [9] as well as adequate peer behavior [10].

However, there is accumulating evidence for a large inter-individual heterogeneity in the development of fluid intelligence. One main focus of the present study is to determine whether this inter-individual heterogeneity may at least partly be influenced by non-cognitive factors, such as individual differences in motivation or temperament. Even though the term 'temperament' does not have a consensual definition, we refer here to Rothbarth's early description as 'constitutionally based individual differences in reactivity and regulation' that energize and direct behavior [11]. The involved temperamental facets are elusive, yet centering on some putative core components, such as approach motivation, impulsivity, and sensation seeking. Approach motivation reflects the 'propensity to move toward (or maintain contact with) desired, rewarding, or positively valenced stimuli' [12], while impulsivity can be defined as the inverse of self-control, thus a 'lack of reflectiveness and planning as well as rapid decision-making and action' [13]. Finally, sensation seeking can be conceptualized as 'a strong willingness to take risks for the sake of varied, novel, and stimulated experiences' [14].

The above-described three temperamental components are interrelated and have often been conflated in previous research [14]. However, they are also separable, and mature along different timetables, especially during childhood and adolescence: Some studies revealed that approach motivation showed a relative stability across late childhood and adolescent development [15,16] while other studies point to an increase in the sensitivity of the behavioral approach system from early (9-12 years) to late adolescence (15-19 years) and a decline in sensitivity of this system after 20 years of age [17]. Age-related changes in impulsivity declined linearly from age 10-12 on up to late adolescence [18-20]. In contrast, the tendency to seek sensation has been shown to increase in early adolescence, especially between 10-12 and 15-19 years of age [20-22] and to decline in early adulthood [20,23].

Relations between the development of fluid intelligence and temperament

Why should temperamental factors influence the development of fluid intelligence? One idea is that individuals with higher approach motivation or need for sensation show a higher activity to explore the environment and a higher need for stimulation of their environment. This may in turn increase the ability to efficiently adapt to environments, which is a key aspect of intelligent behavior. So far there is some first evidence that individual differences in motivation and temperament are related to individual differences in fluid abilities and predictive to later academic outcomes in childhood and adolescence [24,25]. For example, children who achieved higher scores on fluid intelligence tests also showed larger motivational effort [26], higher self-regulatory skills [27], or a larger tendency to seek for novelty and complexity [28]. Similarly, using structural-equation modeling, [29] identified two latent factors, one cognitive factor (i.e. fluid intelligence/ reasoning and working memory) and one temperamental factor (i.e. sensation seeking, impulsiveness, and lack of fear), that both were predictive of academic performance in 13-year-old adolescents. Following this line of research, the present study aimed to investigate whether inter-individual differences in fluid intelligence are modulated by individual differences in the above described three components of temperament (approach motivation, impulsivity, sensation seeking) throughout adolescent development.

There is only little research that has directly addressed the potential role of approach motivation for fluid mental activites. As approach motivation seems to boost purposeful efforts and self-efficiency [30], it may, on the one hand, facilitate task performance, such as reasoning activities. On the other hand,

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approach motivation has been linked to risky behavior in adolescents [16], and in turn may also hamper reasoning activities. For instance, [31] investigated 11-12 year-old children and found a positive relation between the Behavioral Activation System [30] and positive feelings in problem-solving situations but did not measure the relation to actual performance in fluid abilities such as required in problem-solving tasks. To our knowledge there is only one study that examined the link between BAS and fluid abilities in a very age-homogeneous sample of 19 year-olds (SD=1.11 years) that did not find a positive correlation between fluid intelligence and behavioral approach motivation [32]. Impulsivity (as opposed to self-control) has been already studied more often in the context of fluid cognition. Some studies found that high impulsivity was related to low reasoning performance, given its interruptive nature on well-conceived behavioral plans in young adults [33] or in young children [34] but not in a sample of 13 year-olds [29]. Similarly to approach motivation, sensation seeking May, on the one hand, open the mind for novel and complex ideas, thus promoting fluid reasoning. On the other hand, sensation seeking may also reduce reflective in favor of exciting decisions and actions, thus undermining playful intellectual performance [14]. However, Colom, et al. [29] found no relation between sensation seeking and fluid abilities in 13-year-olds. In sum, so far only a few studies examined relations between fluid reasoning and different aspects of temperament. Therefore, we applied different measures of fluid resoning as well as temperament in the present study in order to determine whether all, none, or only specific aspects of individual differences in temperament are related to performance in reasoning tasks.

Moreover, most of the mentioned studies only investigated a very homogenous age sample. From a developmental perspective, a number of recent dual-system models [35-37] for a review Shulman et al., assumed different developmental trajectories for a subcortically mediated ‘hot’ motivational-temperamental system and a prefrontally mediated ‘cold’ cognitive system. The earlier maturation of the motivational system than the cognitive control system leads to a predominant responsiveness to energetic, appetitive goals and positive rewards in mid-adolescence. Hence, it is conceivable that if both systems are interacting [35], the relations among them will change during adolescence development.

In summary, the present study aimed to examine the influence of individual differences in three prominent facets of temperament (i.e., approach motivation, impulsivity, and sensation seeking) on fluid intelligence above and beyond age. We were hereby interested in both their unique contributions as well as their shared influence on fluid intelligence. Furthermore, we aimed to investigate if the relationship between temperamental difficulties and fluid intelligence would vary as a function of age.

1) In line with previous findings on age-related changes in fluid intelligence [4-6] we predicted that fluid intelligence would show a positive linear relationship with age in our adolescent sample. Also in line with previous findings on age-related changes in different aspects of temperament we expected either a linear increase [17] or relative stability for approach motivation [15,16] a linear decline for impulsivity [37] see also [20], and a linear increase for sensation seeking from childhood to mid- or late adolescence [37].

2) Of most interest of the present study was whether the different facets of temperament would have unique and different contributions to fluid intelligence (i.e., in strength or direction) beyond the effects of age. It was an open question whether approach motivation and sensation seeking would show a positive or negative direction of relationship with fluid intelligence, while impulsivity should show a negative direction of this relationship [33]. Finally, we also explored whether the relationship between fluid intelligence and temperament (in common and for each temperamental facets separately) would vary as a function of age.

Materials and Methods

Participants

One hundred eighty eight children and adolescents (mean age=13.7 years, SD=2.87, 97 female) between age 9 and 18 participated in this study. They were recruited from the subject pool of our research unit at Saarland University, as well as via flyers and newspaper advertisements. Participants received 8 € per hour as monetary compensation and a small reward that they could choose themselves at the end of one session measuring cognitive performance and decision-making. Informed consent was given by the participant’s parents or themselves when they were 18 years or older, in accordance with the protocols approved by the local ethics committee.

Four participants were excluded from analysis because of missing data in one or more tests and tasks. Thus, the final sample consisted of 184 participants. Table 1 shows the characteristics of the final sample, including the number of participants in each of the ten age groups, gender ratio, and socioeconomic status (SES).

Procedure

To assess fluid intelligence in children and adolescents, we used three common fluid intelligence tasks that are described in detail in the next section. Participants conducted the tasks in the context of a larger cross-sectional and longitudinal study in order to investigate the development of cognitive control and temperamental functioning over the course of adolescence (age range=9-18 years). The first measurement time T1 consisted of three sessions. In one session participants received a comprehensive test-battery, including different cognitive and three decision-making tasks that lasted about 2-3 hours. These tests and tasks were conducted on a Dell Vostro 430 PC using a Fujitsu Siemens P19-2-Monitor, a computer-keyboard and a response-box. In two further sessions we collected EEG data and measured task switching and reversal learning that will be reported elsewhere. Participants further completed various online self-report questionnaires conducted with the software program SoSci Survey [38]. These questionnaires collected information about, for example, demographic characteristics, or traits such as reward responsiveness and were filled out at home between the sessions. Most importantly for the present study, we also captured self-report questionnaires of approach motivation, impulsivity, and sensation seeking.

Table 1. Descriptive statistics for the participants.

Descriptive statistics for the participants										
	Age group									
Statistic	9-year-olds	10-year-olds	11-year-olds	12-year-olds	13-year-olds	14-year-olds	15-year-olds	16-year-olds	17-year-olds	18-year-olds
n	18	14	16	21	20	19	19	13	24	20
Females/ Males	07-Nov	03-Nov	08-Aug	Aug-13	10-Oct	09-Oct	08-Nov	07-Jun	13-Nov	14-Jun
Mean age (days)	3494.5	3908.6	4251.4	4605.5	4996.8	5330.4	5692.3	6072.9	6417.3	6797.3
	-97.6	-100.5	-105.2	-121.7	-109.7	-82.1	-107.42	-119.8	-93.4	-99.3
SES (SD)	12.5 (2.7)	12.9 (2.2)	12.0 (2.4)	12.1 (2.2)	12.2 (2.8)	13.9 (2.2)	12.6 (2.3)	12.6 (2.2)	11.9 (2.7)	12.8 (2.8)
Note: Mean scores with standard deviations in brackets.										

Fluid intelligence tasks

Advanced progressive matrices: To assess fluid intelligence, we used a computerized version of the Raven's Advanced Progressive Matrices [39]. Each item was presented as a pattern of six figures arranged in a 3 × 3 matrix, one figure missing. Figures ranged from simple geometrical scales to complex patterns. Participants were instructed to select one of eight figures (one target, seven distractor items) below the matrix that would complete the pattern best. Following three practice items, the participants had to solve 36 test items which were increasing in difficulty. As test scores we used the number of correctly solved items within 15 minutes.

Figural reasoning: To further assess fluid intelligence in children and adolescence, we used an adaption of the Figural Reasoning test from items followed the format "F1 relates to F2 as F3 relates to?" and were presented on a computer screen [40]. The stimulus was presented in the upper panel of the screen and participants were instructed to select one of five response alternatives (one target, four distractor items that were presented in the lower panel) that would complete the pattern best. Following the three practice items, the participants had eight minutes to solve as many test items as possible (maximum 24 items) that were also increasing in difficulty. In case of three consecutive errors the task stopped automatically. Test scores referred to the number of correctly solved items.

Letter series: As a third test to measure fluid intelligence, we used an adaption of the Letter Series task from. Items were derived from the ADEPT [40,41]. The stimulus was presented in the upper panel of the screen and consisted of five letters followed by a question mark (e.g., a, c, e, g, i, ?). The items followed a simple rule (e.g.,+1 or-2). Participants were instructed to select the letter that would logically fill the position of the question mark by choosing one of five response alternatives (one target, four distractor items). Following three practice items, the task was automatically stopped when participants committed three consecutive errors or after answering all of the 12 items. As test scores we used the number of correctly solved items.

Because the correlations between the three intelligence tasks were high (Raven APM, Figural Reasoning: r=.57; Raven APM, Letter Series: r=.55; Figural Reasoning, Letter Series: r=.39; all correlations: p<.001), we aggregated them into a composite score. We further assured the one-way structure of the three tasks by executing a factor analysis. Both the Kaiser-Meyer-Olkin test (KMO=.66) and Bartlett's test for sphericity (Chi2 (3)=136.85, p<.001) confirmed that the correlational matrix was suitable for factor analysis. The number of factors has been defined to one factor based on the eigenvalues (>1.0) in combination with the scree-test. Table 2 shows the means and standard deviations for the composite score and the three intelligence tasks separately for each age group.

Self-report measures on approach motivation, impulsivity, and sensation seeking

Behavioral activation system scales: We used a translated version of the Behavioral Activation System (BAS) Scales [30] to assess approach motivation. The BAS contains three subscales Reward Responsiveness (5 items), Drive (4 items), and Fun Seeking (4 items). The items reflect statements (e.g. 'When I want something, I usually go all out to get it') that are answered via a four point Likert scale, ranging from 1 ('strongly disagree') to 4 ('strongly agree'). As we were interested in approach motivation in general, we builded a BAS-Total Score summarizing the point values of each item. Three items were excluded from further analyses (see section below). Therefore, the possible range of point values of this scale was 10-40. In this study, internal consistency reached an alpha-coefficient of .80 for the whole sample which can be seen sufficient.

Impulsiveness questionnaires: We used the subscale Impulsivity of the german adaption of the Impulsiveness Questionnaire I6 [42] originally developed in English [43]. The IVE is a self-assessment questionnaire consisting of three subscales: Impulsivity, Venturesomeness, and Empathy, with 16 items each. According to Eysenck, items to measure impulsivity describe actions which arise on the spur of the moment and can be risky. The items consist of statements about the participant's behavior (e.g., 'I often do or say something without thinking about it'), which they could declare to be true ('Yes') or not ('No'). The possible range of point values of this scale was 0-16. In this study, the internal consistency reached an alpha-coefficient of .82 for the whole sample.

Because impulsivity also implies a lack of self-control, we further assessed impulsivity by using the the German adaption of the Self-Control Scale (SCS) [44,45]. The SCS-K-D is a self-assessment questionnaire with 13 items. The

Table 2. Mean Performance (SD) in fluid intelligence tasks and means (SD) for approach motivation, impulsivity, and sensation seeking as a function of age group.

	Age group									
Measure	9-year-olds	10-year-olds	11-year-olds	12-year-olds	13-year-olds	14-year-olds	15-year-olds	16-year-olds	17-year-olds	18-year-olds
Raven APM	21	29	32	35	38	40	48	54	53	53
	-1.99	-4.08	-3.29	-3.28	-3.25	-3.77	-3.39	-3.09	-3.34	-4.49
Figural reasoning	53	52	57	69	66	69	68	71	78	80
	-5.69	-7.09	-5.54	-3.56	-4.45	-5.52	-6	-8.15	-3.21	-3.55
Letter series	37	37	51	49	58	53	65	65	69	68
	-5.44	-6.86	-8.07	-7.11	-4.3	-7.38	-5.64	-9.01	-5.27	-6.27
Fluid composite score	37	39	47	51	54	54	61	63	67	67
	-2.87	-4.73	-4.85	-6.67	-2.5	-4.65	-3.87	-5.44	-3.09	-4
Approach motivation	34.06	32.71 (1.15)	31.50 (1.03)	32.81 (0.80)	31.05 (0.59)	30.32 (1.30)	30.68 (1.06)	32.77 (1.18)	31.58 (1.33)	31.75 (0.87)
	-0.91									
IVEsubscale impulsivity	9.06 (1.06)	7.57 (1.29)	6.25 (0.87)	7.90 (0.79)	8.15 (0.72)	7.11 (0.93)	6.32 (0.76)	6.46 (1.26)	7.88 (0.52)	5.95 (1.03)
SCS-K-D	32.39 (1.84)	30.21 (2.28)	32.56 (1.91)	36.76 (1.15)	34.85 (1.59)	32.95 (1.71)	34.32 (2.04)	31.00 (2.70)	37.67 (1.57)	33.15 (1.77)
Impulsivity composite	0.14 (0.24)	-0.20 (0.29)	-0.22	0.27 (0.15)	0.18 (0.16)	-0.08 (0.22)	-0.10 (0.21)	-0.29 (0.32)	0.26 (0.13)	-0.22 (0.22)
			-0.21							
Sensation seeking	7.28 (0.71)	9.00 (1.13)	6.94 (1.43)	9.67 (0.74)	9.90 (0.84)	10.32 (0.64)	10.00 (0.87)	9.23 (1.36)	11.46 (0.69)	9.45 (0.71)

Note: Mean performance in fluid intelligence tasks (in %) with standard deviations in brackets. Self-report scales of approach motivation, impulsivity and sensation seeking. Possible range of values for approach motivation is 10-40, for the IVE subscale impulsivity 0-16, for the SCS-K-D 12-60, for sensation seeking 0-15. The composite score of impulsivity represents z-scores (standardized for the whole sample).

Table 3. Intercorrelations among the main study variables across the entire sample with and without out partialled age.

Intercorrelations among the main study variables across the entire sample with and without out partialled age.					
Measure	**1**	**2**	**3**	**4**	**5**
1. Age (days)	----				
2. fluid intelligence	.511**	----	-0.135	-.231**	-.160*
3. Approach Motivation	-0.114	-.173*	----	0.191	0.187
4. Impulsivity	-0.023	-.211**	.192**	----	.347**
5. Sensation seeking	.230**	-0.017	.155*	.332**	----
Note: Intercorrelations with age group partialled out are presented above the diagonal, general intercorrelations are presented below the diagonal. *p < .05. **p < .01, ***p < .001.					

Table 4. Results of hierarchical regression analysis predicting the fluid intelligence composite from age, approach motivation, impulsivity, sensation seeking, and interactions

Criterion fluid intelligence composite						
Predictor	**R**	**R²**	**ΔR²**	**ΔF**	**β**	**t**
Step 1	0.511	0.261	0.261	64,325***		
Age (A)					0.511	8.02***
Step 2	0.558	0.311	0.05	4.321**		
Age (A)					0.515	7.953***
Approach Motivation (AM)					-0.073	-1.134
Impulsivity (I)					-0.162	-2.419*
Sensation Seeking (S)					-0.07	-1.021
Step 3	0.571	0.326	0.014	1.259		
Age (A)					0.522	7.959***
Approach Motivation (AM)					-0.06	-0.92
Impulsivity (I)					-0.175	-2.563*
Sensation Seeking (S)					-0.053	-0.744
A × AM					-0.087	-1.301
A × I					-0.68	-0.981
A × S					0.009	0.136
Note: p-values are two-tailed. *p < .05, **p < .01, ***p < .001						

items consist of statements about participant's behavior (e.g. 'I often act without thinking through all the alternatives') and are answered via a five-point Likert scale, ranging from 1 ('strongly disagree') to 5 ('strongly agree'). One item was excluded from analysis (see section below). Therefore, the possible range of point values of this scale was 12-60. Internal consistency of this scale reached an alpha-coefficient of .80 for the whole sample. Because the correlations between the two impulsivity questionnaires was high (r=.58, p<.001), we again aggregated them into a composite score.

Sensation seeking questionnaire: To assess sensation seeking, we used the subscale Venturesomeness of the German adaption of the IVE [42] originally developed in English [43]. The items consisted of statements about the participant's behavior (e.g., 'I sometimes like to do something risky'), which they could declare to be true ('Yes') or not ('No'). One item was excluded from further analyses (see section below). Therefore, the possible range of point values in this scale was 0-15. In this study, internal consictency was again sufficient, reaching an alpha-coefficient of .80 for the whole sample.

We performed a factor analysis with three fixed factors to identify the highest factor loadings of the items on the postulated three-way structure of temperament (see Introduction). Items loading higher on another factor than the facet-specific factors were excluded from further analyses (for example the BAS-Item "I often act, without thinking for a long time" showed the highest loading on the postulated impulsivity-factor. This led to the exclusion of five items from analysis. Table 3 shows means and standard deviations of each temperament facet separately for each age group.

Data analysis

The present study examined the influence of individual differences in three facets of temperament (approach motivation, impulsivity, and sensation seeking) on fluid intelligence beyond age.

First, we investigated the developmental time course of fluid intelligence and the three temperamental facets separately. For the first hypothesis, we conducted separate linear regression analyses (direct entry) with age (in days) as predictor and the fluid intelligence composite score, or the temperamental facet scores respectively, as criterion.

Second and more importantly, we aimed to evaluate the incremental impact of the temperamental factors on fluid intelligence beyond age, by exploring both their single influence as well as their shared influence on fluid intelligence. Third, we investigated whether the relationship between the three facets of temperament and fluid intelligence would vary as a function of age. The results section is structured along our main questions.

To investigate the second and third hypothesis, we performed one hierarchic (step-wise) multiple linear regression analysis by adding the predictors (i.e. age in days, each temperamental facet score, and the interaction terms) consecutively in three sequent steps. As criterion, we used the composite score of fluid intelligence.

To prevent multicollinearity between the predicting variables, age (in days) and the values of the temperamental facets were converted to z-scores [46]. All analyses were conducted using SPSS (Version 22).

Results

Regarding the growth in fluid intelligence as a function of age, there was, as expected by our first prediction, a significant positive relationship of age and the fluid intelligence composite (β =.51, t(182)=8.02, p<.001). Age accounted for 26% of the variance in the fluid intelligence composite (F(1, 182)=64.33; p<.001).

Regarding the three linear regression analyses evaluating by direct entry whether the separate temperamental facets would change as a function of age, we obtained the following result pattern: Against our expectations, there was no significant relationship between approach motivation and age (β =-.11, t(182)=-1.55, p=.12) and no significant relationship between impulsivity and age (β =-.02, t (182) =-.31, p=.76). Yet as expected, there was a significant positive relationship between sensation seeking and age (β =.23, t (182)=3.19, p<.01).

To answer the question, whether temperament would predict fluid intelligence incrementally beyond age (step 2 of the hierarchical regression analysis), we found, as expected, that the overall model reached significance (F(4, 179)= 20.20; p<.001) with a significant change in R2 (R2 change=.05; F(3, 179)=4.32; p<.01) accounting for 5% more of the variance in the fluid intelligence composite. In this model, there was only a significant negative relationship of impulsivity and the fluid intelligence composite (β =-.16, t (179)=-2.42, p<.05). Neither approach motivation nor sensation seeking reached significance (Table 4).

Regarding the third hypothesis, whether the relationship between temperament and fluid intelligence would change as a function of age, our analyses testing the interaction terms (step 3 of the hierarchical regression analysis) revealed that even though the overall model reached significance, neither the change in R2 nor any of the interaction terms reached significance (Table 4).

Discussion

The present study examined whether individual differences in three prominent facets of temperament (i.e., approach motivation, impulsivity, and sensation seeking) predict individual differences in fluid intelligence above and beyond age, and whether this relationship varied across adolescent development.

In summary, the results of our study revealed, first, in line with our predictions, a significant positive relationship of age and fluid intelligence, suggesting a linear increase of fluid intelligence from childhood to late adolescence. Second, neither approach motivation nor impulsivity changed with age, while sensation seeking showed the expected linear increase from childhood to late adolescence. Third, also in line with our predictions, the temperamental difficulties had an incremental impact on fluid intelligence beyond age. Importantly, this temperamental influence on fluid intelligence seemed to be heavily driven by the impulsivity facet, while approach motivation and sensation seeking did not reveal significant unique contributions. Finally, the relationship between temperament and fluid intelligence did not vary as a function of age.

Our first result of a positive relationship between age and fluid intelligence in our adolescent sample is in line with established literature [5,6] and fits nicely into developmental models of fluid cognition [7,47], claiming a linear increase of fluid abilities even throughout adolescence. This increase has been associated with a further maturation of prefrontal and parietal networks up to early adulthood [48].

Empirical evidence on developmental changes in different facets of temperament was more inconsistent with current literature. In our cross-sectional study we found that approach motivation was not sensitive to age, which was in line with longitudinal data showing high stability in this facet of temperament across a 2-year interval throughout adolescence [15-17]. However, we also found no age-related changes in a composite measure of impulsivity, in contrast to other studies that reported that self-reported impulsive behavior declined with increasing age during adolescence [19,20,48,49]. Yet, impulsivity measures are differentially sensitive to age changes. In line with this argument, it has also been noted that impulsivity seems to be in general a relatively complex, heterogeneous construct, with a high risk for task-impure measurement [42]. This methodical limitation of task impurity will be discussed further below. Either way, our impulsivity measure may also have captured primarily interindividual differences in dispositional trait aspects of impulsivity (and so may have our measure for approach motivation) that, in turn, serves to explain interindividual differences in stable aspects of fluid intelligence. Still in line with the literature, sensation seeking showed an increase from childhood to early adolescence [20-23].

An important new insight of the present study was that individual differences in temperament, and in particular impulsivity, had an additional influence on the fluid intellectual capacity beyond age-related changes in adolescents. Only a few researchers so far have investigated systematically the influence of temperamental variables on cognition, and these have focused on academic performance instead of more basic fluid-reasoning processes [29]. Yet, basic fluid operations are correlated with other fundamental cognitive abilities in childhood and adolescence, such as executive-control functioning [50-54] specifically in children: [1,53]. Executive control is a generic term that refers itself to multiple general-purpose mechanisms that interact to enable individuals to guide their thoughts and actions in accordance with internal and external goals, tasks, and intentions [53]. Such control processes aid the orchestration of basal sensory, motor, emotional, and cognitive processes in support of producing intelligent behavior in novel and difficult situations or contexts [55]. Given the mutual links of basic fluid intelligence with such other fundamental cognitive operations, our results may have implications for the general relationship between temperament and cognition in adolescence.

Regarding the variance portions in fluid intelligence explained uniquely by each temperamental subfacet, we only found a selective significant negative relation between fluid intelligence and impulsivity. Impulsivity, as compared to approach motivation or sensation seeking, has a strong conceptual proximity to the afore-mentioned construct of executive control. Already by definition, impulsivity can be described as the 'inverse of self-control capacity'. From an empirical point of view [56] revealed (amongst others) an inverse relationship between fluid intelligence and impulsivity, suggesting reduced processing capacity (also measured with neural indicators, such as event-related brain potential techniques) with larger impulsivity. The authors proposed that higher impulsivity may hamper the resistance to interfering information, thus reducing processing efficiency and the remaining capacity for (fluid) cognitive operations [57]. Hence, impulsivity may have more cognitive share than approach motivation and sensation seeking that are mainly driven by energetic, motivational processes and show less genuine overlap with basic cognition.

Against our assumptions, we found no age-related changes in the relationship between temperament and fluid intelligence, although dual-system theories [35-37,58] predict different developmental trajectories for motivational-temperamental and cognitive processes across childhood and adolescence. However, in the present study, our analyses on the developmental trajectories within each temperamental subfacet already were not in line with previous research [19-20,37,49].

This study faces some of limitations including the following ones. First, the study relies on a number of constructs (i.e., fluid intelligence, approach motivation, impulsivity, sensation seeking) that may, by themselves, not fit a single-factor structure, especially not across varying ages. For example, [59] showed how the single-factor structure in cognitive functions may best fit to data from children of preschool and early middle age ranges, while in school age and adolescence, there might be a drastic increase in the differentiation of separable cognitive components above and beyond a common cognitive factor

[59]. Although we carefully considered the dimensionality of each construct across ages in the present study (see in the methods section), future studies should further examine age-related changes in the factorial structure.

Moreover, both the reasoning tasks as well as the temperamental questionnaire measures are at risk of being process-impure as mentioned earlier [60]. Reuter-Lorenz et al. [60] proposed that 'a latent variable approach can be used to address the impurity problem with statistical methods that extract common variance across multiple tasks targeting the same putative' functions [60]. Therefore, future studies with sufficiently large sample sizes should countervalidate our findings based on structural equation modeling techniques.

Conclusion

Furthermore, it should be noted that we investigated developmental changes based on cross-sectional data, whereas future studies should test our research questions based on longitudinal data.

To conclude, our study specifically revealed an incremental impact of impulsivity but not approach motivation and sensation seeking, on fluid intelligence beyond age, while this relationship remained stable over time. Our findings may help specify the tripartite relationship between age, temperament, and cognition in adolescence.

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Ethical Statement

We affirm that we obtained informed consent and complied with APA ethical standards in the treatment of participants: Informed consent was given by the participant's parents or themselves when they were 18 years or older, in accordance with the protocols approved by the local ethics committee.

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