Eat2beNICE

Effects of Nutrition and Lifestyle on Impulsive, Compulsive, and Externalizing Behaviours

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Executive Summary

We have completed and published a manuscript about associations of nutrition and physical activity with impulsive behaviour in a sub-sample of the Estonian Psychobiological Study of Traffic Behaviour (EPSTB; n = 817). It was concluded in the study that there are significant associations between risk-taking/impulsive behaviour in traffic (exceeding speed limit) and aspects of lifestyle (e.g. alcohol/junk-food consumption and physical activity). In addition, aggressiveness and variation in the serotonergic system appeared to be mediating and moderating factors of these associations. The manuscript was published in 2022:

> Tokko, T., Eensoo, D., Luht-Kallas, K., Harro, J. (2022). Risk-taking in traffic is associated with unhealthy lifestyle: Contribution of aggressiveness and the serotonin transporter genotype. *Neuroscience Applied, 1*, 100110. https://doi.org/10.1016/j.nsa.2022.100110.

We have completed and published a manuscript about associations of diet, cardiorespiratory fitness and impulsivity in a sample of Estonian Children Personality Behaviour and Health Study. We identified associations between several (micro)nutrients, cardiorespiratory fitness and maladaptive impulsivity and concluded that food choices may affect the neurochemistry and therefore may regulate the manifestations of impulsivity. The manuscript was published in 2022:

> Matrov, D., Kurrikoff, T., Villa, I., Sakala, K., Pulver, A., Veidebaum, T., Shimmo, R., Harro, J. (2022). Associations of Impulsivity with Food, Nutrients and Fitness in a Longitudinal Birth Cohort Study. *International Journal of Neuropsychopharmacology,* pyac052, https://doi.org/10.1093/ijno/pyac052

Manuscripts are inserted below as part of this report.

Abbreviations

5-HTTLPR	Serotonin transporter gene-linked polymorphic region
ADHD	Attention deficit hyperactivity disorder
AMIS	Adaptive and Maladaptive Impulsivity Scale
ASRS	Adult ADHD Self Report Scale
AUDIT	Alcohol Use Disorders Identification Test
BMI	Body mass index
BPAQ	Buss-Perry Aggression Questionnaire
CFI	Comparative Fit Index
DAS	Driving Anger Scale
DWI	Driving while impaired by alcohol
EPSTB	Estonian Psychobiological Study of Traffic Behaviour
PPPE	Problematic practice of physical exercise
RMSEA	Root Mean Square Error of Approximation
TLI	Tucker Lewis index
VNTR	Variable number of tandem repeats

CINP	The International College of Neuropsychopharmacology
ADHD	Attention-deficit/hyperactivity disorder
AMIS	Adaptive and Maladaptive Impulsivity Scale
BMI	Body mass index
MPO/kg bwt	Maximal power output calculated per kilogram of body weight
W	Workload
bpm	Beats per minute
rpm	Revolutions per minute
mL	Milliliter
EDTA	Ethylenediaminetetraacetic acid
K3	Tripotassium
mmol/l	Millimoles per liter
mU/L	Milliunits per liter
HDL	High-density lipoprotein
LDL	Low-density lipoprotein
EFA	Exploratory factor analysis
CFA	Confirmatory factor analysis
LMM	Linear mixed effects approach
y	Year
n	Sample size
kg bwt	Per kilogram of body weight
g	Gram
mg	Milligram
µg	Microgram
CI	Confidence interval
P	Probability
R^2	Coefficient of determination
NEOPI-R	Revised Neuroticism, Extraversion, Openness Personality Inventory
ECPBHS	Estonian Children Personality Behaviour and Health Study
NMDA	N-methyl-D-aspartate
UK	United Kingdom
IJNPPY	International Journal of Neuropsychopharmacology

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Research Articles

Risk-taking in traffic is associated with unhealthy lifestyle: Contribution of aggressiveness and the serotonin transporter genotype

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ABSTRACT

Objectives: Risk taking behaviour, including in traffic, is related to impulsivity and aggressiveness, and so is unhealthy lifestyle. The serotonin transporter gene promoter polymorphism (5-HTTLPR) has been associated with impulsivity, aggression, alcohol use, speed limit exceeding and traffic accidents. The aim of this study was to examine whether subjects with less healthy eating and exercise habits take more risks in traffic, and whether impulsivity, aggressiveness and the serotonin transporter genotype could mediate or moderate any such associations.

Method: A sub-sample of the Estonian Psychobiological Study of Traffic Behaviour (EPSTB (n = 817) with mean age (SD) = 31.4 (10.0) years filled out lifestyle questionnaires. Impulsivity was measured by Adaptive and Maladaptive Impulsivity Scale and aggressiveness by Buss – Perry Aggression Questionnaire. Traffic violation data in the previous 5 years period were obtained from police database.

Results: Speed limit exceeders had higher physical and verbal aggression, higher AUDIT scores, they reported more vigorous physical activity and drinking energy drinks more often. Path analysis showed that higher AUDIT scores were associated with speeding via higher physical aggression. 5-HTTLPR was not directly associated with speeding or driving while impaired by alcohol (DWI), but 5-HTTLPR s'-allele carriers had lower AUDIT scores if they were not junk food eaters and the other way around, while l'/l' homozygosity was associated with DWI via higher AUDIT scores.

Conclusion: Significant associations exist between risky traffic behaviour and aspects of lifestyle such as consumption of alcohol or junk food or energy drinks, as well as engagement in vigorous physical activity, while traits such as aggressiveness and the variation in the serotonergic system appear as mediating and moderating factors. Interventions preventing accidents should focus on wider array of behaviours and use personalized approach. Genetic variation should be investigated regarding associations with risk taking and health behaviour, and response to interventions.

1. Introduction

Road traffic injuries remain a serious public health issue. Traffic accidents often result from risk taking behaviour that is based on behavioural traits such as impulsivity and aggressiveness (Constantinou et al., 2011; Biçaksiz and Özkan, 2016; Antić et al., 2018). Impulsive and aggressive behaviour have also been found associated with health behaviours like exercising and maintaining a healthy diet. For example, impulsivity has consistently been found related to not only overeating and food addiction (Loxton, 2018) but also to greater fast food consumption (Garza et al., 2016). Fast food/junk food is any food, which is low in essential nutrients and high in everything else - in particular, calories and sodium (Segen's Medical Dictionary, 2022). Consumption of energy drinks, which contain high amounts of caffeine and sugar, is another example of questionable diet: Associations have been found between energy drink consumption and higher perceived stress, smoking and alcohol abuse, poor quality of sleep, increased blood pressure, and risk of obesity and type 2 diabetes (Ali et al., 2015; Al-Shaar et al., 2017; Gunja and Brown, 2012; Wolk et al., 2012). Among possible mediating mechanisms, aggressive behaviour and sensation seeking are both

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associated with energy drinks consumption (Azagba et al., 2014; Hamilton et al., 2013). While physical exercise brings about multiple benefits to health, problematic practice of physical exercise (PPPE, also known as exercise addiction or exercise dependence) is a maladaptive pattern of excessive exercise behaviour that manifests in physiological, psychosocial, and cognitive symptoms (Hausenblas and Downs, 2002). Associations of PPPE with negative urgency and sensation seeking have also been found, and it has been suggested that PPPE serves to regulate or alleviate negative affect or aversive emotional states (Kotbagi et al., 2017).

Expectedly, attention deficit hyperactivity disorder (ADHD), with one of the core symptom domains being hyperactivity/impulsivity (DSM 5), has also been associated with traffic accidents and violations (Kittel-Schneider et al., 2019; Vaa, 2014), and we have recently found in independent samples that while approximately 12% of drivers have high ADHD risk by the ASRS screening score (Kessler et al., 2005), they also have more of recorded traffic accidents and violations (Tokko et al., 2022). Furthermore, people with ADHD symptoms also have higher rates of self-reported unhealthy lifestyles (e.g., alcohol/drug abuse, smoking, poor diet), and worse general health (Björk et al., 2018; Weissenberger et al., 2018). Lifestyles like these can result in different health problems (obesity, hypertension, heart disease), in addition to risky behaviour (Weissenberger et al., 2018).

Animal studies strongly suggest that poor dietary choices may influence neurodevelopmental trajectories during adolescence (Reichelt and Rank, 2017). More specifically, alterations in dopamine-mediated reward signalling and GABA-ergic inhibitory neurotransmission can occur and predispose individuals to dysregulated eating and impulsive behaviours Diets high in processed fat and sugar induce impulsive choice behaviour (Steele et al., 2017). Evidence also indicates that the relationship between somatic markers (body fat percentage, insulin, and inflammation) and impulsive choice is indeed moderated by diet, and the combination of such bodily measures and diet is most predictive of an impulsive choice (Steele, 2019).

Impulsive behaviour has most consistently been associated with low capacity of the central serotonergic system (Evenden, 1999; Fairbanks et al., 2001), and the serotonin transporter plays the crucial role in serotonergic neurotransmission. The serotonin transporter gene promoter polymorphism (5-HTTLPR) (Heils et al., 1995) has been associated with impulsivity (Steiger et al., 2005; Paaver et al., 2008), aggression (Gerra et al., 2005; Gonda et al., 2009), alcohol use (Merenäkk et al., 2011; Vaht et al., 2014; Eduardo Coral de Oliveira et al., 2016), suicide (Gonda et al., 2010) speed limit exceeding and traffic accidents (Eensoo et al., 2018). Some evidence exists that diets poor in the serotonin precursor tryptophan may induce depression (Shabbir et al., 2013), and acute tryptophan depletion has been shown to increase impulsivity in males (Walderhaug et al., 2002; Dougherty et al., 2010). The short (s) allele of the serotonin transporter gene promoter region polymorphism (5-HTTLPR) has been found to be a marker of less efficient serotonergic functioning, but being a common variant, it is not surprising that besides the risk behaviours it also confers higher adaptivity to the environment (Homberg and Lesch, 2011). Tryptophan depletion and the s-allele of 5-HTTLPR have been reported to be independently and additively associated with impulsivity (Walderhaug et al., 2010). We have previously shown that the 5-HTTLPR s'-allele carriers have less violations and accidents in traffic, compared to l'/l' homozygotes (Eensoo et al., 2018), and lower adaptive impulsivity (Luht et al., 2019). It should however be noted that different markers of serotonergic capacity associate with the impulsivity profiles in e.g., drunk drivers vs speed limit exceeders (Paaver et al., 2006).

The aim of this study was to test the hypothesis that higher impulsivity leads to both less healthy lifestyle and taking risks while driving a car in traffic, the latter resulting in traffic violations and/or accidents. We also examined the possibility that the 5-HTTLPR polymorphism underlies the eventual associations (Fig. 1).

2. Method

2.1. Sample

A link to the web-based questionnaire was sent by e-mail in 2019 to all subjects of the Estonian Psychobiological Study of Traffic Behaviour (EPSTB). EPSTB comprises several samples recruited in four originally independent projects: Samples of drunk drivers (Eensoo et al., 2005) and speed limit exceeders (Paaver et al., 2006) with driver's license registry based controls, and two samples of traffic school students (Luht et al., 2019; Paaver et al., 2013). In brief, these samples had originally been formed as follows: The samples drunk drivers (Eensoo et al., 2005) and speed limit exceeders (Paaver et al., 2006) were formed of the male subjects from the police database of driving violations and control groups were formed of male subjects with a valid driving licence in the driving licence database by computerised random choice. Controls were screened for any police records. Two samples of traffic school students (Luht et al., 2019; Paaver et al., 2013) comprised driving school students applying for a passenger car driving license. All of the subjects who filled out the questionnaires were included in the current study. Altogether 817 subjects agreed to participate, with the mean age (SD) = 31.4 (10.0) years); 49.2% males and 50.8% females. For this study subjects' age was calculated by adding 5 years to their age as it was in the beginning of their study, because we have information from databases about subjects' accidents and violations for a 5-year period since the beginning of study for each sample. The proportions of subjects by the year their study started were as follows: 2001, n = 183 (22%); 2007, n = 285 (35%); 2013/2014, n = 349 (43%).

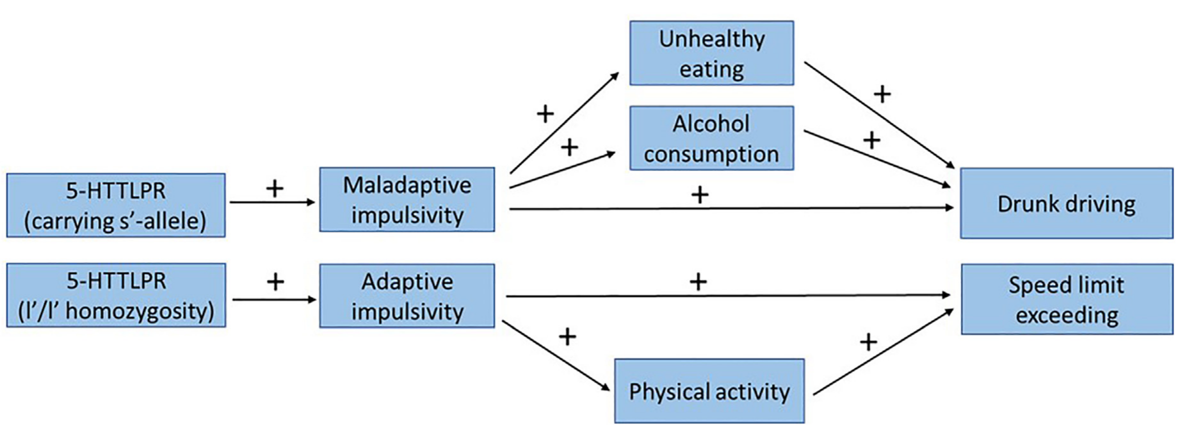

Fig. 1. Schematic representation of the hypothesis of the study.

2.2. Questionnaires

2.2.1. Impulsivity measures

The Adaptive and Maladaptive Impulsivity Scale (AMIS) was used to measure different facets of impulsivity (fast decision making, thoughtlessness, disinhibition, excitement seeking) as previously described (Laas et al., 2010). AMIS is based on the concept of functional and dysfunctional impulsivity by Dickman (1990). Subjects were asked to assess how much the 24 impulsivity-related statements applied to them on a scale from 1 to 5. Questionnaire was filled out by subjects in the beginning of the study and data were available for 774 subjects.

2.2.2. Aggressiveness and driving anger

The Buss–Perry Aggression Questionnaire (BPAQ) (Buss and Perry, 1992) is a widely used measure of aggressiveness. The 29-item instrument assesses four aspects of aggressive behaviour: Physical aggression, Verbal aggression, Anger, and Hostility. Participants rated each statement on a 5-point Likert Scale (uncharacteristic = 1, characteristic = 5). Buss-Perry Aggression Questionnaire was filled out by all subjects in 2019, and data were available for 744 subjects.

The Driving Anger Scale (DAS 33) (Deffenbacher et al., 1994) includes 33 potentially angering traffic situations and queries how much anger does each provoke on a scale from 0 to 4 (0 = none at all, 1 = a little, 2 = some, 3 = much, 4 = very much). Driving Anger Scale was filled out by subjects in the beginning of the study and data were available for 568 subjects.

2.2.3. Eating questionnaire

Subjects answered questions about the frequency (1–7, never – several times in a day) of eating different foods and drinking energy drinks in the past few weeks. We calculated the used the mean score of eating of French fries and hamburgers as an indicator of fast/unhealthy eating (junk food consumption, n = 816). As an indicator of healthy eating, we used the question about the frequency of eating vegetables (n = 806). In addition, we included the frequency of energy drink consumption (at least once a week vs less than once a week; n = 816) in the analysis. Data were available for all subjects included in the analysis.

2.2.4. Physical activity and body mass index

Subjects were asked about their physical activity in the past week. In this study we used “vigorous physical activity” as a measure. Vigorous physical activity was defined as activities that require great physical energy and make the subject breathe a lot faster than regularly (e.g., doing hard work, exercising). The activity had to last at least 10 min consecutively, and it was asked how much time the participants spent in the past week on these kinds of activities (hours per week). In addition, body mass index (BMI) was calculated by data provided by subjects about their weight and height (BMI = kg/m^2). Data about physical activity were available for 812 and about BMI for 777 subjects.

2.2.5. Alcohol consumption (AUDIT)

The Alcohol Use Disorders Identification Test (AUDIT) (Saunders et al., 1993) was used to identify subjects who have problematic alcohol consumption. The test contains 10 multiple choice questions on quantity and frequency of alcohol consumption, drinking behaviour, and alcohol-related problems or reactions (scale 0–4). In the analysis the total score was used. Data were available for 744 subjects.

2.3. Databases

Traffic insurance and police databases were used to obtain data about traffic collisions and traffic violations of the participants for the respective five-year period since the recruitment of each sample. For speeding violations and drunk driving (driving while intoxicated by alcohol - DWI) we also used the sum of violations in this five-year period, so that the score could be from 0 (no speeding tickets/drunk driving violations) to 5 (received at least one speeding/drunk driving violation ticket every year).

2.4. Genotyping

Genotyping for the triallelic classification of the 5-HTTLPR polymorphism was performed according to Anchordoquy et al. (2003). Genotyping was performed in two stages. First, all subjects were genotyped for the 5-HTTLPR VNTR polymorphism, then for the single nucleotide polymorphism (SNP) rs25531 (A/G). The polymorphic region was amplified using the primers 5-HTTLPR-F: 5′-6FAM-ATG CCA GCA CCT AAC CCC TAA TGT-3′ and 5-HTTLPR-R: 5′-GGA CCG CAA GGT GGG CGG GA-3′. Then SNP rs25531 (A→G) was determined as described in detail elsewhere (Tomson et al., 2011). Triallelic 5-HTTLPR genotypes were categorised into groups according to the effectiveness at the transcriptional level as follows: l_G/l_G, l_G/s, and s/s were designated as s’/s’; l_A/s and l_A/l_G as l’/s’; and l_A/l_A as l’/l’. Genotype frequencies were in the Hardy–Weinberg equilibrium. We compared the s’ allele carriers with the l’/l’ homozygotes (n = 644, s’/l’ – 49.2%, l’/l’ – 32.0%, s'/s'– 18.8%).

2.5. Statistical analysis

Data were analysed using SPSS (version 23.0 SPSS, Chicago, IL) and SAS (version 9.4 SAS Inc., Cary, NC) software. Normality of data was assessed visually by box plots, Q-Q plots and also by skewness and kurtosis. Differences between groups regarding categorical variables were analysed with Pearson's chi-square test and the post-hoc Fisher's test, and for continuous variables with Student's t-tests if data was normally distributed and with Mann-Whitney *U* Test for data which did not follow normal distribution. Logistic regression analyses were used for predicting speed limit exceeding. First, simple logistic regression analyses were conducted with each independent variable, and next, independent variables were adjusted by gender.

To obtain insight into the complex relationship between traffic violations and accidents, genotype, impulsivity, eating and physical health behaviour, structural equation modelling (SEM) was used. For multiple imputation of missing cases Full Information Maximum Likelihood Estimation (FIML) was used. Fit indices and their acceptable thresholds used values as Root Mean Square Error of Approximation (RMSEA) less than 0.07 (Steiger, 2007), Comparative Fit Index (CFI) and Tucker Lewis index TLI greater than 0.95 (Sharma et al., 2005). The $p < 0.05$ level was considered as statistically significant in all the analyses.

Correction for multiple testing was not used in this study.

3. Results

3.1. Health behaviour, impulsivity and aggressiveness

Demographic, health and traffic behavioural measures are presented in Table 1 separately for males and females. The males in our sample were significantly older than females. Males reported to eat less vegetables and had a higher body mass index, but regarding junk food consumption there was no significant gender difference. Males also had a higher AUDIT score and were to a greater extent engaged in vigorous physical activity per week. Regarding impulsivity and aggressiveness measures, males had higher scores in adaptive impulsivity (fast decision making and excitement seeking), but lower scores on the disinhibition subscale of maladaptive impulsivity. Males reported higher physical and verbal aggression, but females reported higher anger and hostility. The driving anger score was higher in males. In addition, males had more

Table 1
Impulsivity and aggressiveness, health and traffic behaviour variables by gender.

	Females	Males	Total	Differences by gender
Age, mean (SD)	29.0 (8.0)	33.9 (11.1)	31.4 (10.0)	**t (725.8) = 7.3, p < 0.001**
Vegetable consumption, mean (SD)	5.02 (1.4)	4.53 (1.2)	4.78 (1.32)	**t (810.9) = -5.5, p < 0.001**
Junk food consumption, median (min; max)	4 (2;8)	4 (2;8)	4 (2;8)	U = 83051.0, p = 0.957
Energy drink consumption (once a week/ more) % (n)	7.0 (29)	10.5 (42)	8.7 (71)	χ^2 = 3.1, p = 0.083
AUDIT score, median (min; max)	3 (0;20)	4 (0;31)	3 (0;31)	**U = 47847.00, p < 0.001**
Physical activity (hours per week), median (min; max)	1.2 (0;56.0)	3 (0;56.0)	2 (0;56.0)	**U = 63344.0, p < 0.001**
BMI (Body mass index), median (min; max)	22.7 (13.8;42.4)	26.3 (15.1;53.2)	24.5 (13.8;53.2)	**U = 43252.0, p < 0.001**
Fast decision making, mean (SD)	17.1 (4.6)	19.4 (4.5)	18.2 (4.6)	**t (772) = 6.9, p < 0.001**
Excitement seeking, mean (SD)	18.4 (5.1)	20.1 (5.2)	19.2 (5.2)	**t (772) = 4.4, p < 0.001**
Thoughtlessness, mean (SD)	15.3 (4.7)	14.7 (4.8)	15.0 (4.7)	t (772) = −1.8, p = 0.075
Disinhibition, mean (SD)	17.7 (4.4)	16.8 (4.7)	17.3 (4.5)	**t (772) = -2.8, p = 0.005**
Physical aggression (Buss-Perry), median (min; max)	13 (9;31)	15 (9;43)	14 (9;43)	**U = 51443.5, p < 0.001**
Verbal aggression (Buss-Perry), mean (SD)	12.2 (3.5)	13.1 (3.8)	12.6 (3.7)	**t (761) = 3.4, p = 0.001**
Anger (Buss-Perry), mean (SD)	15.0 (5.1)	13.6 (4.7)	14.3 (5.0)	**t (761) = -3.8, p < 0.001**
Hostility (Buss-Perry), mean (SD)	17.2 (5.5)	16.3 (4.9)	16.7 (5.2)	**t (753.7) = -2.4, p = 0.017**
Driving anger score (DAS 33), mean (SD)	52.9 (26.8)	61.1 (25.3)	57.4 (26.3)	**t (566) = 3.8, p < 0.001**
Traffic accidents (active), % (n)	12.0 (50)	23.1 (93)	17.5 (143)	**χ^2 = 17.4, p < 0.001**
Traffic accidents (passive), % (n)	8.4 (35)	23.9 (96)	16.0 (131)	**χ^2 = 36.2, p < 0.001**
Traffic accidents (all), % (n)	17.6 (73)	37.3 (150)	27.3 (223)	**χ^2 = 40.0, p < 0.001**
Traffic violations (speeding), % (n)	5.8 (24)	28.1 (113)	16.8 (137)	**χ^2 = 72.9, p < 0.001**
Traffic violations (DWI), % (n)	0.2 (1)	4.2 (17)	2.2 (18)	**χ^2 = 15.1, p < 0.001**
Traffic violations (all), % (n)	12.3 (51)	47.0 (189)	29.4 (240)	**χ^2 = 118.7, p < 0.001**
High traffic risk, % (n)	24.6 (101)	65.7 (249)	44.3 (350)	**χ^2 = 117.9, p < 0.001**

Significant differences are marked in bold; DWI – driving while impaired by alcohol; Means are presented for differences calculated by Student's t-test, medians for differences calculated by Mann-Whitney *U* test and percentages for differences calculated by Pearson's chi-square test and the post-hoc Fisher's test.

accidents and violations in traffic. With regard to high traffic risk (accidents + violations), 65.7% of males had accidents and/or violations in the five-year period, vs 24.6% of females.

3.2. Health behaviour, impulsivity and aggressiveness in speed limit exceeders

Exceeding the speed limits is a most common traffic violation, and it was consistently associated with measures of impulsivity, aggressiveness and health behaviour (Table 2). Speed limit exceeders had higher scores of fast decision making (t (772) = −5.0, p < 0.001) and excitement seeking (t (772) = −6.1, p < 0.001), physical and verbal aggression (U = 28899.0, p < 0.001 and t (761) = −4.7, p < 0.001, respectively) compared to subjects with no speeding tickets in the 5-year period, but they were not significantly different in maladaptive impulsivity (thoughtlessness and disinhibition), anger or hostility. Speeding subjects also had higher AUDIT score (U = 32587.0, p = 0.005), they reported doing more vigorous physical activity (U = 34710.0, p < 0.001) and drinking energy drinks more often ($\chi2$ = 7.21, p = 0.007). Speed limit exceeders also had significantly more violations of other type, and higher prevalence of traffic accidents.

3.3. Gender differences in exceeding speed limits

We conducted logistic regression either unadjusted or adjusted for gender as there were significant gender differences in demographic and traffic behavioural variables (Table 1). Logistic regression, when adjusted for gender, rendered several of the previous significant associations with speeding, such as AUDIT score, BMI and DWI not statistically significant (Table 3). Several other associations remained significant even after adjustment, such as energy drink consumption, vigorous physical activity, adaptive impulsivity and aggression/anger scores as well as the frequency of traffic accidents occurrence.

Table 2
Speed limit exceeding: Impulsivity and aggressiveness, health and traffic behaviour.

	Control group	Speed limit exceeders
Gender, male % (n)	42.5 (289)	82.5 (113)***
Age, mean (SD)	31.2 (9.8)	32.4 (10.4)
Vegetable consumption, mean (SD)	4.80 (1.33)	4.69 (1.29)
Junk food consumption, median (min; max)	4 (2;8)	4 (2;8)
Energy drink consumption, once a week or more, % (n)	7.5 (51)	14.6 (20)**
Alcohol problems (AUDIT), median (min; max)	3 (0;31)	4 (0;24)**
Vigorous physical activity, hours per week, median (min; max)	2 (0;56)	3 (0;36)***
BMI (Body mass index), median (min; max)	24.2 (13.8;47.2)	26.3 (15.1;53.2)**
Fast decision making, mean (SD)	17.9 (4.6)	20.0 (4.5)***
Excitement seeking, mean (SD)	18.8 (5.2)	21.7 (4.6)***
Thoughtlessness, mean (SD)	14.9 (4.7)	15.3 (5.0)
Disinhibition, mean (SD)	17.2 (4.5)	17.4 (4.8)
Physical aggression (Buss-Perry), median (min; max)	13 (9;43)	16 (9;40)***
Verbal aggression (Buss-Perry), mean (SD)	12.3 (3.6)	14.0 (4.0)***
Anger (Buss-Perry), mean (SD)	14.1 (4.9)	15.0 (5.3)
Hostility (Buss-Perry), mean (SD)	16.7 (5.2)	16.8 (5.5)
Driving anger score (DAS 33), mean (SD)	55.7 (26.4)	64.6 (24.7)**
Traffic accidents (all), % (n)	22.2 (151)	52.6 (72)***
Traffic violations (DWI), % (n)	1.5 (10)	5.8 (8)**
Traffic violations (other), % (n)	14.7 (100)	47.4 (65)***

*p < 0.05, **p < 0.01, ***p < 0.001 statistically significant difference. Means are presented for differences calculated by Student's t-test, medians for differences calculated by Mann-Whitney *U* test and percentages for differences calculated by Pearson's chi-square test and the post-hoc Fisher's test.

Table 3
Logistic regression models predicting speed-limit exceeding.

	Speeding	Speeding[a]
Age	1.01 (0.99–1.03)	0.99 (0.97–1.01)
Gender, male vs female	**6.37 (4.00–10.15)**	-
Vegetable consumption, mean (SD)	0.94 (0.82–1.08)	1.06 (0.91–1.24)
Junk food consumption	1.18 (0.99–1.41)	1.18 (0.99–1.41)
Energy drink consumption, once a week vs less	**2.11 (1.21–3.66)**	**1.89 (1.05–3.40)**
Alcohol problems (AUDIT) score	**1.04 (1.01–1.08)**	1.00 (0.93–1.05)
Vigorous physical activity, hours per week	**1.04 (1.01–1.06)**	**1.03 (1.00–1.05)**
BMI (Body mass index)	**1.06 (1.02–1.09)**	1.01 (0.98–1.05)
Fast decision making score	**1.11 (1.06–1.16)**	**1.08 (1.03–1.13)**
Excitement seeking score	**1.13 (1.08–1.18)**	**1.11 (1.06–1.16)**
Thoughtlessness score	1.01 (0.98–1.06)	1.03 (0.99–1.07)
Disinhibition score	1.01 (0.97–1.05)	1.03 (0.99–1.07)
Physical aggression score (Buss-Perry)	**1.09 (1.05–1.12)**	**1.06 (1.02–1.10)**
Verbal aggression score (Buss-Perry)	**1.13 (1.07–1.19)**	**1.11 (1.05–1.17)**
Anger score (Buss-Perry)	1.03 (1.00–1.07)	**1.06 (1.02–1.11)**
Hostility score (Buss-Perry)	1.00 (0.97–1.04)	1.02 (0.98–1.06)
Driving anger score (DAS 33)	**1.01 (1.01–1.02)**	**1.01 (1.00–1.02)**
Traffic accidents all	**3.88 (2.65–5.68)**	**2.95 (1.98–4.40)**
Traffic violations (DWI), yes vs no	**4.16 (1.61–10.73)**	2.30 (0.87–6.04)
5-HTTLPR (n = 644) La/La vs S allele	0.94 (0.61–1.45)	1.04 (0.77–1.41)

[a] adjusted for gender; Bold - significant predictor; odds ratio (OR) with 95 percent confidence intervals (CI).

3.4. Drunk driving (DWI)

There were 18 subjects in the sample who had a drunk driving violation in the 5-year period, and 17 of them were male. So, when comparing drunk drivers with subjects who had no drunk driving violations, we included only male subjects (n = 402; Table 4).

Table 4
Demographic and traffic behaviour variables in males by DWI.

Independent variable	No DWI (n = 384)	DWI (n = 17)
Age, mean (SD)	33.9 (11.2)	32.3 (9.3)
Vegetable consumption, mean (SD)	4.6 (1.2)	3.9 (1.2)*
Junk food consumption, mean (SD)	3.9 (1.1)	4.2 (1.6)
Energy drink consumption, once a week or more, % (n)	10.4 (40)	11.8 (2)
Alcohol problems (AUDIT), median (min; max)	4 (0;31)	4 (3;31)*
Vigorous physical activity, hours per week, median (min; max)	3 (0;56)	2 (0;30)
BMI (Body mass index), median (min; max)	26.3 (15.1;53.2)	26.0 (19.9;38.6)
Fast decision making, mean (SD)	19.4 (4.4)	18.2 (5.1)
Excitement seeking, mean (SD)	20.0 (5.2)	21.2 (6.8)
Thoughtlessness, mean (SD)	14.6 (4.8)	16.1 (5.0)
Disinhibition, mean (SD)	16.7 (4.7)	19.3 (4.3)*
Physical aggression (Buss-Perry), median (min; max)	15 (9;43)	16 (10;40)
Verbal aggression (Buss-Perry), mean (SD)	13.0 (3.8)	14.5 (4.5)
Anger (Buss-Perry), mean (SD)	13.5 (4.6)	15.8 (6.4)
Hostility (Buss-Perry), mean (SD)	16.1 (4.8)	18.8 (5.1)*
Driving anger score (DAS 33), mean (SD)	60.9 (25.5)	69.5 (15.0)
Traffic accidents (all), % (n)	23.9 (127)	23.5 (4)
Traffic violations (speeding), % (n)	27.3 (105)	47.1 (8)
Traffic violations (other), % (n)	32.5 (125)	70.6 (12)**

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$ statistically significant difference. Means are presented for differences calculated by Student's t-test, medians for differences calculated by Mann-Whitney *U* test and percentages for differences calculated by Pearson's chi-square test and the post-hoc Fisher's test.

Drunk drivers were significantly different by their higher disinhibition ($t(381) = -2.2$, $p = 0.029$), an aspect of maladaptive impulsivity. Drunk drivers also had higher hostility ($t(375) = -2.2$, $p = 0.026$) and significantly more other traffic violations (70.6% vs 32.5%, $\chi 2 = 10.53$, $p = 0.001$ compared to drivers with no DWI violation. Drunk drivers had higher AUDIT scores (mean rank = 240.9 vs 181.2, $U = 2008.5$, $p = 0.023$) and they reported eating less vegetables than subjects with no drunk driving violation ($t(399) = 2.2$, $p = 0.028$).

3.5. Search for a path from the 5-HTTLPR to traffic violations

In this sample neither drunk drivers nor speed limit exceeders differed by the frequencies of the 5-HTTLPR genotypes, but when we compared l'/l' homozygotes with s'-allele carriers by other variables there were some differences: l'/l' homozygotes had significantly higher AUDIT scores (mean rank = 315.5 vs 285.8, $U = 33305.5$, $p = 0.049$) and reported eating less junk food (mean (SD) = 3.7 (0.9) vs 3.9 (1.1), $t(642) = -2.3$, $p = 0.02$), and additionally male l'/l' homozygotes had higher driving anger scores as compared to s'-allele carriers (mean (SD) = 64.1 (23.9) vs 57.3 (25.6), $t(262) = 2.0$, $p = 0.04$). Considering these differences and our hypothesis, we conducted structural equation modelling path analysis to uncover any indirect association of 5-HTTLPR with risky traffic behaviour and health behaviour measures. The results of this analysis suggested that those 5-HTTLPR l'/l' homozygotes who have more problematic alcohol consumption and a higher score in physical aggression are more likely to speed in traffic (Fig. 2A). Those 5-HTTLPR s'-allele carriers who eat junk food more often join the path as consuming more alcohol and are more likely to speed in traffic. In addition, subjects who are more engaged in strenuous physical activity (sports/hard work) had increased physical aggression and speeding. All of the associations in the model were statistically significant ($p < 0.05$), with a good fit to the model (RMSEA = 0.009, CFI = 0.99, TLI = 0.99).

Considering the notable differences in risk-taking behaviour between males and females (Tables 1 and 3), path models for males and females were constructed separately. The path model for males again revealed l'/l' homozygotes to have more speed limit exceeding mediated by AUDIT score and physical aggression, but also by driving anger with almost all of the associations in the model being significant with the exception of path from 5-HTTLPR to AUDIT score ($p = 0.056$) (Fig. 2B; RMSEA = 0.027, CFI = 0.95, TLI = 0.85).

Path analysis in females did not point at any role of the 5-HTTLPR, but energy drink consumption appeared as a significant predictor for speed limit exceeding on its own (Fig. 2C) as well as mediated through a higher AUDIT score and verbal aggression, and all of the associations in the model were statistically significant (RMSEA = 0.000, CFI = 1.00, TLI = 1.11).

Path analysis for drunk driving also revealed an indirect association with l'/l' homozygosity and drunk driving via higher AUDIT score (Fig. 3). In addition, eating less vegetables remained as a separate significant indicator of being a drunk driver. Although fit to the model was good, the paths from 5-HTTLPR to AUDIT score and 5-HTTLPR to drunk driving were not significant ($p = 0.055$ and 0.390 respectively) (RMSEA = 0.000, CFI = 1.00, TLI = 1.54).

4. Discussion

We have found that people who have higher impulsivity and/or aggressiveness violate traffic rules more often and also tend to be generally more reckless in their health behaviour. Exceeding speed limits was consistently associated with both personality factors and health behaviours. Speeding is a good example of a result of potentially impulsive decision-making in traffic and has possible dangerous outcomes (Elvik, 2012; Theofilatos and Yannis, 2014) and our data are consistent with speed limit exceeders having substantially more traffic accidents as compared with subjects who had no speeding tickets.

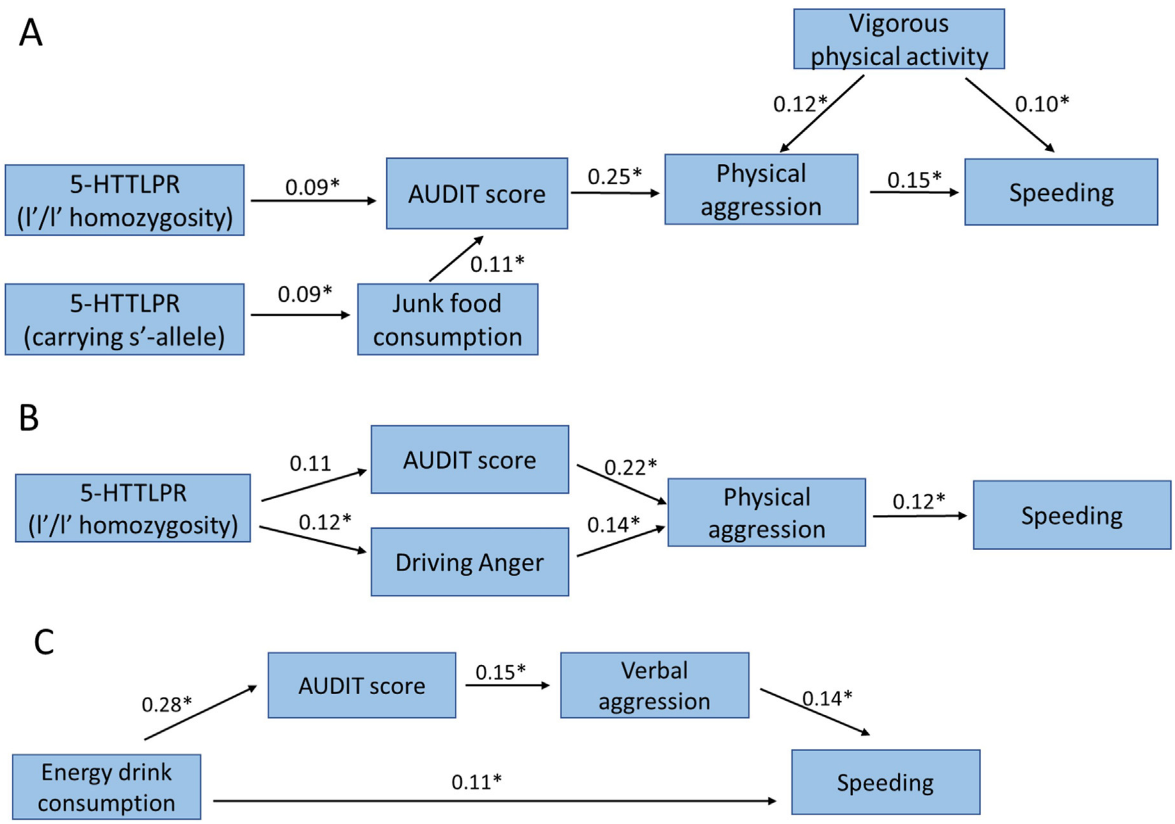

Fig. 2. Path analysis models for exceeding speed limits. A – the whole sample (n = 817), B - males (n = 402), C - females (n = 415).

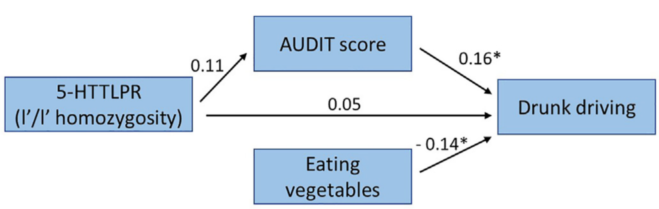

Fig. 3. Path analysis model from 5-HTTLPR to drunk driving (males; n = 402).

We have previously reported that speed limit exceeders have higher scores in facets of adaptive impulsivity (Paaver et al., 2006), and the present investigation extends this to aggressiveness. Higher aggressiveness among speeding subjects has also been shown before (Öz et al., 2010; Greaves and Ellison, 2011; Sârbescu and Rusu, 2021), and the use of Buss – Perry Aggression Questionnaire in the current study adds to this evidence with higher physical and verbal aggression of speed limit exceeders. Interestingly, speed limit exceeding was also associated with higher involvement in vigorous physical activity, both directly and mediated by physical aggression. Animal experiments has shown that exercise can effectively alleviate ADHD-like symptoms through enhancing dopamine D_2 receptor expression in the brain (Sam Cho et al., 2014), and it has been suggested that exercise may serve as as a way of counteractive regulation of impulsive behaviours (Racine, 2012). It has also been shown that adults with ADHD engaging in frequent aerobic physical activity report significantly less behavioural impulsivity compared to subjects with low activity (Abramovitch et al., 2013). In addition, Joseph et al. (2011), have concluded that increased physical activity may help compensate and suppress the hedonic drive to over-eat. The results of this study do not suggest that speeding is a behaviour truly compensated for or suppressed by physical activity; rather exercising appears as being fuelled at least in part by similar mechanisms as the risky behaviour of speeding, and it is generally descriptive of the profile of someone with higher adaptive impulsivity.

Associations of lifestyle with aggression have also been shown before, with higher aggression levels among subjects with unhealthy lifestyles (sleeping less, poor eating habits, drinking, smoking, not working out) (Kim et al., 2020; Pouyamanesh, 2013; Rao et al., 2015). In a study using the Buss – Perry Aggression Questionnaire, the subjects with poor lifestyle had higher physical aggression, hostility, and anger, but those with healthier habits reported higher verbal aggression (Pouyamanesh, 2013). In the present study both physical and verbal aggression predicted speeding behaviour, but the former being a significant mediator in males and the latter in females. Even though we did not find a direct link between higher physical aggression, speeding and accidents in males, we did find that males had significantly more accidents in traffic as compared to females. Gender differences of physical vs verbal aggression in speeding behaviour appears consistent with previous studies which have found that females express their anger in traffic more constructively than males (González-Iglesias et al., 2012; Sullman, 2015; Hernández-Hernández et al., 2019). Thus, speeding in males and females is in part differently mediated and possibly for this reason more often resulting in accidents in males, because in traffic, higher physical aggression represents potentially more dangerous behavioural tendencies.

Overall, while speed limit exceeding was not directly associated with eating habits, drunk drivers reported eating less healthy foods by the example of vegetable consumption. Drunk drivers also had higher maladaptive impulsivity, as previously reported (Paaver et al., 2006), and aggressiveness measures. On the basis of previous studies on impulsivity and compulsive behaviour, we hypothesized that carriers of the 5-HTTLPR s'-allele would have higher maladaptive impulsivity and unhealthier eating habits, higher alcohol consumption and possibly also drunk driving, while 5-HTTLPR l'/l' homozygotes might be prone to speeding. No simple association of the genotype with traffic behaviour was found. Admittedly the sample of subjects, especially with DWI, was small for this type of analysis. However, the path analysis models have suggested that the genotypes have both common and unique aspects in the path to traffic violations, contributing indirectly. The path of both l'/l' homozygotes and s'-allele carriers leading to exceeding the speed limits included excessive use of alcohol and tendency of physical aggression, while the speeding s'-allele carriers also had less healthy dietary habits. A path specifically for the l'/l' homozygotes leading through problematic alcohol use to drunk driving could also be established. It is obvious that both s'-allele carriers and l'/l' homozygotes can exhibit both types of traffic violations, but speeding and drunk driving by l'/l' homozygotes may occur in other contexts as of the s'-allele carriers, given their difference in aspects of impulsive and compulsive behaviour (Paaver et al., 2008; Walderhaug et al., 2007; Hong et al., 2018; Sinopoli et al., 2019). It should be noted that while drunk drivers in this study had higher frequency of other violations, they did not differ significantly in terms of involvement in traffic accidents. Further, in the path analysis with males, speeding among l'/l' homozygotes was still associated with higher AUDIT scores, driving anger and physical aggression, but in females the association with energy drink consumption, higher AUDIT score and verbal aggression had no relationship to the 5-HTTLPR genotype. All together, the 5-HTTLPR l'/l' homozygotes who had a record of either drunk driving or speeding were likely to be abusers of alcohol, and this was observable in males, although likely due to the decreased statistical power because of smaller sample size all of the associations were not separately significant. The 5-HTTLPR s'-allele carriers had a speeding record if they also presented further aspects of unhealthy lifestyle, here in the form of junk food eating. These findings are consistent with the view that the 5-HTTLPR l'/l' homozygotes are behaviourally less flexible while the s'-allele carriers have higher sensitivity to the environmental context (Homberg and Lesch, 2011); on the other hand, behaviour of the 5-HTTLPR l'/l' homozygotes may become more controlled by alcohol (Kapitau et al., 2019).

The previously reported association between consumption of energy drinks and high-risk behaviour (Hamilton et al., 2013) was also observable in the present study, and the association was stronger among those with higher AUDIT scores. That energy drink consumption is linked to high-risk behaviour particularly when combined with alcohol has also been observed (Breda et al., 2014). In traffic behaviour co-use of these beverages appeared particularly significant in females. Previously it has been found that high habitual caffeine consumers report greater trait-wise motor impulsivity, but acute caffeine intake did not influence response inhibition or impulsive, risky, or aggressive behaviour in high or low habitual caffeine consumers (Giles et al., 2016). So, it may be hypothesized that the consumption of energy drinks does not by itself induce risk-taking behaviour in traffic but is a behavioural tendency that accompanies those who take more risks.

As a limitation of the current study, it has to be pointed out that for a proportion of the subjects the data collection was carried out in different time windows. Impulsivity has been shown to decline steadily with age (Steinberg et al., 2008; Forrest et al., 2019), but the decline is more pronounced in the younger years, and it is unlikely that subjects of our study had a significant decline after the age of 30. Similarly, eating habits have been found to form already early during childhood (Nicklaus et al., 2005), and exercise behaviour to be moderately to highly stable across the life span (van der Zee et al., 2019). Therefore, it is also rather unlikely that the results of the study would have been affected substantially by this limitation of the database. It would have been desirable to know the diet in more detail, e.g., the intake of saturated fatty acids and sugar, but we doubted that it could be reliably reported by the participants. Therefore we focused on some of the most simple aspects of dietary choices which would reflect healthy and unhealthy behaviour.

5. Conclusion

In conclusion, several aspects of lifestyle like junk food consumption and physical activity were associated with taking risks and violating the rules in traffic. These maladaptive behavioural patterns appear to form around impulsive tendencies and develop along distinct patterns that in part vary by genetically encoded differences in neural circuits and include the gender factor. It might be beneficial to consider the constellations of the larger spectrum of health-related behaviours and the diversity of their mediating mechanisms in future interventions. This study expands our knowledge of the factors that are associated with behaviour in traffic and brings up research topics for the future, such as whether interventions that focus only on one behavioural aspect (e.g., traffic) should be converted into more comprehensive, and more personalized, approaches to lifestyle. Future interventions should, by means of promoting self-regulation skills, bring about a general change of behavioural habits in risk groups. The personalized aspect can be derived from understanding the genetic/biological variability that could inform about response to different types of intervention.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Abramovitch, A., Goldzweig, G., Schweiger, A., 2013. Correlates of physical activity with intrusive thoughts, worry and impulsivity in adults with attention deficit/hyperactivity disorder: a cross-sectional pilot study. Isr. J. Psychiatry Relat. Sci. 50, 47–54.

Al-Shaar, L., Vercammen, K., Lu, C., Richardson, S., Tamez, M., Mattei, J., 2017. Health effects and public health concerns of energy drink consumption in the United States: a mini-review. Front. Public Health 5. https://www.frontiersin.org/article/10.3389/fpubh.2017.00225.

Ali, F., Rehman, H., Babayan, Z., Stapleton, D., Joshi, D.-D., 2015. Energy drinks and their adverse health effects: a systematic review of the current evidence. Postgrad. Med. 127, 308–322. https://doi.org/10.1080/00325481.2015.1001712.

Anchordoquy, H.C., McGeary, C., Liu, L., Krauter, K.S., Smolen, A., 2003. Genotyping of three candidate genes after whole-genome preamplification of DNA collected from buccal cells. Behav. Genet. 33, 73–78. https://doi.org/10.1023/A:1021007701808.

Antić, B., Čabarkapa, M., Čubranić-Dobrodolac, M., Čičević, S., 2018. The influence of aggressive driving behavior and impulsiveness on traffic accidents. Int. J. Transp. Eng. 8, 372–389.

Azagba, S., Langille, D., Asbridge, M., 2014. An emerging adolescent health risk: caffeinated energy drink consumption patterns among high school students. Prev. Med. 62, 54–59. https://doi.org/10.1016/J.YPMED.2014.01.019.

Biçaksiz, P., Özkan, T., 2016. Impulsivity and driver behaviors, offences and accident involvement: a systematic review. Transport. Res. F Traffic Psychol. Behav. 38, 194–223. https://doi.org/10.1016/J.TRF.2015.06.001.

Björk, A., Rönngren, Y., Selander, J., Vinberg, S., Hellzen, O., Olofsson, N., 2018. Health, lifestyle habits, and physical fitness among adults with ADHD compared with a random sample of a Swedish general population. Soc. Heal. Vulnerability. 9. https://doi.org/10.1080/20021518.2018.1553916.

Breda, J.J., Whiting, S.H., Encarnação, R., Norberg, S., Jones, R., Reinap, M., Jewell, J., 2014. Energy drink consumption in Europe: a review of the risks, adverse health effects, and policy options to respond. Front. Public Health 2. https://www.frontiersin.org/article/10.3389/fpubh.2014.00134.

Buss, A.H., Perry, M., 1992. The aggression questionnaire. J. Pers. Soc. Psychol. 63, 452–459. https://doi.org/10.1037/0022-3514.63.3.452.

Constantinou, E., Panayiotou, G., Konstantinou, N., Loutsiou-Ladd, A., Kapardis, A., 2011. Risky and aggressive driving in young adults: personality matters. Accid. Anal. Prev. 43, 1323–1331. https://doi.org/10.1016/J.AAP.2011.02.002.

Deffenbacher, J.L., Oetting, E.R., Lynch, R.S., 1994. Development of a driving anger scale. Psychol. Rep. 74, 83–91. https://doi.org/10.2466/pr0.1994.74.1.83.
Dickman, S.J., 1990. Functional and dysfunctional impulsivity: personality and cognitive correlates. J. Pers. Soc. Psychol. 58, 95–102. https://doi.org/10.1037/0022-3514.58.1.95.
Dougherty, D.M., Richard, D.M., James, L.M., Mathias, C.W., 2010. Effects of acute tryptophan depletion on three different types of behavioral impulsivity. Int. J. Tryptophan Res. 3. https://doi.org/10.4137/IJTR.S4317. IJTR.S4317.
Eduardo Coral de Oliveira, C., Massayo Maeda Oda, J., Batista Ariza, C., Losi Guembarovski, R., Karina Banin Hirata, B., Campos de Almeida, F., Delgado André, N., Helena Pelegrinelli Fungaro, M., Angelica Ehara Watanabe, M., 2016. Genetic polymorphism in the promoter region of serotonin transporter: implications for ethanol abuse in children and adolescents. J. Can. Acad. Child Adolesc. Psychiatry 25, 43–49.
Eensoo, D., Paaver, M., Harro, M., Harro, J., 2005. Predicting drunk driving: contribution of alcohol use and related problems, traffic behaviour, personality and platelet monoamine oxidase (mao) activity. Alcohol Alcohol 40, 140–146. https://doi.org/10.1093/alcalc/agh135.
Eensoo, D., Paaver, M., Vaht, M., Loit, H.M., Harro, J., 2018. Risky driving and the persistent effect of a randomized intervention focusing on impulsivity: the role of the serotonin transporter promoter polymorphism. Accid. Anal. Prev. 113, 19–24. https://doi.org/10.1016/j.aap.2018.01.021.
Elvik, R., 2012. Speed limits, enforcement, and health consequences. Annu. Rev. Publ. Health 33, 225–238. https://doi.org/10.1146/annurev-publhealth-031811-124634.
Evenden, J.L., 1999. Varieties of impulsivity. Psychopharmacology 146, 348–361. https://doi.org/10.1007/PL00005481.
Fairbanks, L.A., Melega, W.P., Jorgensen, M.J., Kaplan, J.R., McGuire, M.T., 2001. Social impulsivity inversely associated with CSF 5-HIAA and fluoxetine exposure in vervet monkeys. Neuropsychopharmacology 24, 370–378. https://doi.org/10.1016/S0893-133X(00)00211-6.
Forrest, W., Hay, C., Widdowson, A.O., Rocque, M., 2019. Development of impulsivity and risk-seeking: implications for the dimensionality and stability of self-control. Criminology 57, 512–543. https://doi.org/10.1111/1745-9125.12214.
Garza, K.B., Ding, M., Owensby, J.K., Zizza, C.A., 2016. Impulsivity and fast-food consumption: a cross-sectional study among working adults. J. Acad. Nutr. Diet. 116, 61–68. https://doi.org/10.1016/J.JAND.2015.05.003.
Gerra, G., Garofano, L., Castaldini, L., Rovetto, F., Zaimovic, A., Moi, G., Bussandri, M., Branchi, B., Brambilla, F., Friso, G., Donnini, C., 2005. Serotonin transporter promoter polymorphism genotype is associated with temperament, personality traits and illegal drugs use among adolescents. J. Neural. Transm. 112, 1397–1410. https://doi.org/10.1007/s00702-004-0268-y.
Giles, G.E., Mahoney, C.R., Brunyé, T.T., Kanarek, R.B., 2016. Cautiously caffeinated: does caffeine modulate inhibitory, impulsive, or risky behavior? J. Caffeine Res. 7, 7–17. https://doi.org/10.1089/jcr.2016.0018.
Gonda, X., Fountoulakis, K.N., Juhasz, G., Rihmer, Z., Lazary, J., Laszik, A., Akiskal, H.S., Bagdy, G., 2009. Association of the s allele of the 5-HTTLPR with neuroticism-related traits and temperaments in a psychiatrically healthy population. Eur. Arch. Psychiatr. Clin. Neurosci. 259, 106–113. https://doi.org/10.1007/s00406-008-0842-7.
Gonda, X., Fountoulakis, K.N., Harro, J., Pompili, M., Akiskal, H.S., Bagdy, G., Rihmer, Z., 2010. The possible contributory role of the S allele of 5-HTTLPR in the emergence of suicidality. J. Psychopharmacol. 25, 857–866. https://doi.org/10.1177/0269881110376693.
González-Iglesias, B., Gómez-Fraguela, J.A., Luengo-Martín, M.Á., 2012. Driving anger and traffic violations: gender differences. Transport. Res. F Traffic Psychol. Behav. 15, 404–412. https://doi.org/10.1016/J.TRF.2012.03.002.
Greaves, S.P., Ellison, A.B., 2011. Personality, risk aversion and speeding: an empirical investigation. Accid. Anal. Prev. 43, 1828–1836. https://doi.org/10.1016/J.AAP.2011.04.018.
Gunja, N., Brown, J.A., 2012. Energy drinks: health risks and toxicity. Med. J. Aust. 196, 46–49. https://doi.org/10.5694/mja11.10838.
Hamilton, H.A., Boak, A., Ilie, G., Mann, R.E., 2013. Energy drink consumption and associations with demographic characteristics, drug use and injury among adolescents. Can. J. Public Health 104, e496–e501. https://doi.org/10.17269/cjph.104.3998.
Hausenblas, H.A., Downs, D.S., 2002. Exercise dependence: a systematic review. Psychol. Sport Exerc. 3, 89–123. https://doi.org/10.1016/S1469-0292(00)00015-7.
Heils, A., Teufel, A., Petri, S., Seemann, M., Bengel, D., Balling, U., Riederer, P., Lesch, K.-P., 1995. Functional promoter and polyadenylation site mapping of the human serotonin (5-HT) transporter gene. J. Neural Transm. Gen. Sect. 102, 247–254. https://doi.org/10.1007/BF01281159.
Hernández-Hernández, A.M., Siqueiros-García, J.M., Robles-Belmont, E., Gershenson, C., 2019. Anger while driving in Mexico city. PLoS One 14, e0223048. https://doi.org/10.1371/JOURNAL.PONE.0223048.
Homberg, J.R., Lesch, K.P., 2011. Looking on the bright side of serotonin transporter gene variation. Biol. Psychiatr. 69, 513–519. https://doi.org/10.1016/J.BIOPSYCH.2010.09.024.
Hong, J.S., Kim, S.M., Bae, S., Han, D.H., 2018. Impulsive internet game play is associated with increased functional connectivity between the default mode and salience networks in depressed patients with short allele of serotonin transporter gene. Front. Psychiatr. 9.
Joseph, R.J., Alonso-Alonso, M., Bond, D.S., Pascual-Leone, A., Blackburn, G.L., 2011. The neurocognitive connection between physical activity and eating behaviour. Obes. Rev. 12, 800–812. https://doi.org/10.1111/j.1467-789X.2011.00893.x.
Kapitau, A., Goloenko, I., Obyedkov, V., Pavlov, K., Dariusz Szajda, S., Waszkiewicz, N., 2019. Serotonin transporter gene linked polymorphism (5-HTTLPR) determines progredience of alcohol dependence in Belarusian young males. Adv. Med. Sci. 64, 169–173. https://doi.org/10.1016/J.ADVMS.2018.08.010.
Kessler, R.C., Adler, L., Ames, M., Demler, O., Faraone, S., Hiripi, E., Howes, M.J., Jin, R., Secnik, K., Spencer, T., Ustun, T.B., Walters, E.E., 2005. The World Health Organization adult ADHD self-report scale (ASRS): a short screening scale for use in the general population. Psychol. Med. 35, 245–256. https://doi.org/10.1017/S0033291704002892.
Kim, K., Yee, J., Kim, J.H., Chung, J.E., Lee, K.E., Song, G., Han, J.M., Gwak, H.S., 2020. Health behaviors associated with aggression in Korean adolescents: data from 2 Cross-sectional Studies. Am. J. Health Behav. 44, 271–282. https://doi.org/10.5993/AJHB.44.2.14.
Kittel-Schneider, S., Wolff, S., Queiser, K., Wessendorf, L., Meier, A.M., Verdenhalven, M., Brunkhorst-Kanaan, N., Grimm, O., McNeill, R., Grabow, S., Reimertz, C., 2019. Prevalence of ADHD in accident victims: results of the PRADA study. J. Clin. Med. 8, 1643. https://doi.org/10.3390/jcm8101643.
Kotbagi, G., Morvan, Y., Romo, L., Kern, L., 2017. Which dimensions of impulsivity are related to problematic practice of physical exercise? J. Behav. Addict. 6, 221–228. https://doi.org/10.1556/2006.6.2017.024.
Laas, K., Reif, A., Herterich, S., Eensoo, D., Lesch, K.P., Harro, J., 2010. The effect of a functional NOS1 promoter polymorphism on impulsivity is moderated by platelet MAO activity. Psychopharmacology 209, 255–261. https://doi.org/10.1007/s00213-010-1793-z.
Loxton, N.J., 2018. The role of reward sensitivity and impulsivity in overeating and food addiction. Curr. Addict. Reports 5, 212–222. https://doi.org/10.1007/S40429-018-0206-Y/TABLES/2.
Luht, K., Tokko, T., Eensoo, D., Vaht, M., Harro, J., 2019. Efficacy of intervention at traffic schools reducing impulsive action, and association with candidate gene variants. Acta Neuropsychiatr. 31, 159–166. https://doi.org/10.1017/neu.2019.2.
Merenäkk, L., Mäestu, J., Nordquist, N., Parik, J., Oreland, L., Loit, H.M., Harro, J., 2011. Effects of the serotonin transporter (5-HTTLPR) and α2A- adrenoceptor (C-1291G) genotypes on substance use in children and adolescents: a longitudinal study. Psychopharmacology 215, 13–22. https://doi.org/10.1007/S00213-010-2109-Z/FIGURES/3.
Nicklaus, S., Boggio, V., Chabanet, C., Issanchou, S., 2005. A prospective study of food variety seeking in childhood, adolescence and early adult life. Appetite 44, 289–297. https://doi.org/10.1016/J.APPET.2005.01.006.
Öz, B., Özkan, T., Lajunen, T., 2010. Professional and non-professional drivers' stress reactions and risky driving, Transp. Res. Part F Traffic Psychol. Beyond Behav. 13, 32–40. https://doi.org/10.1016/J.TRF.2009.10.001.
Paaver, M., Eensoo, D., Pulver, A., Harro, J., 2006. Adaptive and maladaptive impulsivity, platelet monoamine oxidase (MAO) activity and risk-admitting in different types of risky drivers. Psychopharmacology 186, 32–40. https://doi.org/10.1007/S00213-006-0325-3/FIGURES/2.
Paaver, M., Kurrikoff, T., Nordquist, N., Oreland, L., Harro, J., 2008. The effect of 5-HTT gene promoter polymorphism on impulsivity depends on family relations in girls. Prog. Neuro Psychopharmacol. Biol. Psychiatr. 32, 1263–1268. https://doi.org/10.1016/J.PNPBP.2008.03.021.
Paaver, M., Eensoo, D., Kaasik, K., Vaht, M., Mäestu, J., Harro, J., 2013. Preventing risky driving: a novel and efficient brief intervention focusing on acknowledgement of personal risk factors. Accid. Anal. Prev. 50, 430–437. https://doi.org/10.1016/j.aap.2012.05.019.
Pouyamanesh, J., 2013. The effect of bad lifestyle on increasing aggression. Procedia - Soc. Behav. Sci. 84, 1634–1638. https://doi.org/10.1016/J.SBSPRO.2013.07.005.
Racine, M., 2012. The Association between Impulsivity and Exercise in Adolescents. doctoral dissertation at Texas A&M University.
Rao, S., Shah, N., Jawed, N., Inam, S., Shafique, K., 2015. Nutritional and lifestyle risk behaviors and their association with mental health and violence among Pakistani adolescents: results from the National Survey of 4583 individuals. BMC Publ. Health 15, 1–9. https://doi.org/10.1186/s12889-015-1762-x.
Reichelt, A.C., Rank, M.M., 2017. The impact of junk foods on the adolescent brain. Birth Defects Res. 109, 1649–1658. https://doi.org/10.1002/bdr2.1173.
Sam Cho, H., Jung Baek, D., Soo Baek, S., 2014. Effect of exercise on hyperactivity, impulsivity and dopamine D 2 receptor expression in the substantia nigra and striatum of spontaneous hypertensive rats. J. Exerc. Nutr. Biochem. 18, 379–384. https://doi.org/10.5717/jenb.2014.18.4.379.
Sârbescu, P., Rusu, A., 2021. Personality predictors of speeding: anger-Aggression and Impulsive-Sensation Seeking. A systematic review and meta-analysis. J. Saf. Res. 77, 86–98. https://doi.org/10.1016/J.JSR.2021.02.004.
Saunders, J.B., Aasland, O.G., Babor, T.F., De La Fuente, J.R., Grant, M., 1993. Development of the alcohol use disorders identification test (AUDIT): WHO collaborative project on early detection of persons with harmful alcohol consumption-II. Addiction 88, 791–804. https://doi.org/10.1111/j.1360-0443.1993.tb02093.x.
Segen's Medical Dictionary. Definition of junk food. https://medical-dictionary.thefreedictionary.com/junk+food. May 5, 2022.
Shabbir, F., Patel, A., Mattison, C., Bose, S., Krishnamohan, R., Sweeney, E., Sandhu, S., Nel, W., Rais, A., Sandhu, R., Ngu, N., Sharma, S., 2013. Effect of diet on serotonergic neurotransmission in depression. Neurochem. Int. 62, 324–329. https://doi.org/10.1016/J.NEUINT.2012.12.014.
Sharma, S., Mukherjee, S., Kumar, A., Dillon, W.R., 2005. A simulation study to investigate the use of cutoff values for assessing model fit in covariance structure models. J. Bus. Res. 58, 935–943. https://doi.org/10.1016/J.JBUSRES.2003.10.007.
Sinopoli, V.M., Erdman, L., Burton, C.L., Park, L.S., Dupuis, A., Shan, J., Goodale, T., Shaheen, S.-M., Crosbie, J., Schachar, R.J., Arnold, P.D., 2019. Serotonin system genes and obsessive-compulsive trait dimensions in a population-based, pediatric

sample: a genetic association study. JCPP (J. Child Psychol. Psychiatry) 60, 1289–1299. https://doi.org/10.1111/jcpp.13079.
Steele, C.C., 2019. Dietary Effects on Impulsive Choice: an Investigation of Physiological Moderators in Rats and Humans. doctoral dissertation at Kansas State University.
Steele, C.C., Pirkle, J.R.A., Kirkpatrick, K., 2017. Diet-induced impulsivity: effects of a high-fat and a high-sugar diet on impulsive choice in rats. PLoS One 12, e0180510. https://doi.org/10.1371/JOURNAL.PONE.0180510.
Steiger, J.H., 2007. Understanding the limitations of global fit assessment in structural equation modeling. Pers. Indiv. Differ. 42, 893–898. https://doi.org/10.1016/J.PAID.2006.09.017.
Steiger, H., Joober, R., Israël, M., Young, S.N., Ng Ying Kin, N.M.K., Gauvin, L., Bruce, K.R., Joncas, J., Torkaman-Zehi, A., 2005. The 5HTTLPR polymorphism, psychopathologic symptoms, and platelet [3H-] paroxetine binding in bulimic syndromes. Int. J. Eat. Disord. 37, 57–60. https://doi.org/10.1002/eat.20073.
Steinberg, L., Albert, D., Cauffman, E., Banich, M., Graham, S., Woolard, J., 2008. Age differences in sensation seeking and impulsivity as indexed by behavior and self-report: evidence for a dual systems model. Dev. Psychol. 44, 1764–1778. https://doi.org/10.1037/A0012955.
Sullman, M.J.M., 2015. The expression of anger on the road. Saf. Sci. 72, 153–159. https://doi.org/10.1016/J.SSCI.2014.08.013.
Theofilatos, A., Yannis, G., 2014. A review of the effect of traffic and weather characteristics on road safety. Accid. Anal. Prev. 72, 244–256. https://doi.org/10.1016/J.AAP.2014.06.017.
Tokko, T., Miškinyte, G., Eensoo, D., Harro, J., 2022. Driving risks of young drivers with symptoms of attention deficit hyperactivity disorder: association with the dopamine transporter gene VNTR polymorphism. Nord. J. Psychiatr. 1–9. https://doi.org/10.1080/08039488.2022.2032330.
Tomson, K., Merenäkk, L., Loit, H.M., Mäestu, J., Harro, J., 2011. The relationship between serotonin transporter gene promoter polymorphism and serum lipid levels at young age in a longitudinal population-representative study. Prog. Neuro Psychopharmacol. Biol. Psychiatr. 35, 1857–1862. https://doi.org/10.1016/j.pnpbp.2011.08.004.
Vaa, T., 2014. ADHD and relative risk of accidents in road traffic: a meta-analysis. Accid. Anal. Prev. 62, 415–425. https://doi.org/10.1016/j.aap.2013.10.003.
Vaht, M., Merenäkk, L., Mäestu, J., Veidebaum, T., Harro, J., 2014. Serotonin transporter gene promoter polymorphism (5-HTTLPR) and alcohol use in general population: interaction effect with birth cohort. Psychopharmacology 231, 2587–2594. https://doi.org/10.1007/S00213-013-3427-8/FIGURES/2.
van der Zee, M.D., van der Mee, D., Bartels, M., de Geus, E.J.C., 2019. Tracking of voluntary exercise behaviour over the lifespan. Int. J. Behav. Nutr. Phys. Activ. 16, 1–11. https://doi.org/10.1186/s12966-019-0779-4.
Walderhaug, E., Lunde, H., Nordvik, J.E., Landrø, N., Refsum, H., Magnusson, A., 2002. Lowering of serotonin by rapid tryptophan depletion increases impulsiveness in normal individuals. Psychopharmacology (Berl) 164, 385–391. https://doi.org/10.1007/s00213-002-1238-4.
Walderhaug, E., Magnusson, A., Neumeister, A., Lappalainen, J., Lunde, H., Refsum, H., Landrø, N.I., 2007. Interactive effects of sex and 5-HTTLPR on mood and impulsivity during tryptophan depletion in healthy people. Biol. Psychiatr. 62, 593–599. https://doi.org/10.1016/J.BIOPSYCH.2007.02.012.
Walderhaug, E., Herman, A.I., Magnusson, A., Morgan, M.J., Landrø, N.I., 2010. The short (S) allele of the serotonin transporter polymorphism and acute tryptophan depletion both increase impulsivity in men. Neurosci. Lett. 473, 208–211. https://doi.org/10.1016/J.NEULET.2010.02.048.
Weissenberger, S., Ptacek, R., Vnukova, M., Raboch, J., Klicperova-Baker, M., Domkarova, L., Goetz, M., 2018. ADHD and lifestyle habits in Czech adults, a national sample. Neuropsychiatric Dis. Treat. 14, 293–299. https://doi.org/10.2147/NDT.S148921.
Wolk, B.J., Ganetsky, M., Babu, K.M., 2012. Toxicity of energy drinks. Curr. Opin. Pediatr. 24, 243–251.

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Association of Impulsivity With Food, Nutrients, and Fitness in a Longitudinal Birth Cohort Study

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Abstract

Background: Impulsivity is a psychiatric vulnerability factor strongly associated with substance abuse but also with unhealthy diet. Whether these associations extend to specific nutrients is largely unknown. Therefore, we investigated the longitudinal association between diet, cardiorespiratory fitness, and 2 impulsivity dimensions in a representative sample of south Estonian adolescents and young adults. Impulsivity and dietary intake were measured 3 times in 2 birth cohorts at regular intervals in individuals aged 15 to 33 years.
Methods: The sample included 2 birth cohorts of the longitudinal Estonian Children Personality Behaviour and Health Study. The analytic sample size consisted of 2883 observations (56.4% females). The primary outcomes were adaptive and maladaptive impulsivity scores measured by an original 24-item Likert-type questionnaire. Impulsivity scores were predicted from the food diaries data converted into nutrient categories. A linear mixed-effects approach was used to model the time dependence between observations.
Results: Lower maladaptive impulsivity was associated with higher cardiorespiratory fitness ($\beta = -.07$; 95% CI = –0.12; –0.03). Higher maladaptive impulsivity was associated with lower dietary intake of zinc ($\beta = -.10$; –0.15; –0.06) and vegetables ($\beta = -.04$; –0.07; –0.01) and higher intake of sodium ($\beta = .06$; 0.02; 0.10). Vitamin B6 was positively associated with adaptive impulsivity ($\beta = .04$; 0.01; 0.07). Additionally, some of the adjusted models showed significant but weak associations with selenium, alcohol, fish, and cereal products.
Conclusions: Food choice may affect the neurochemistry and therefore regulate the manifestations of impulsivity. We identified associations between several (micro)nutrients and maladaptive impulsivity.

Keywords: Impulsivity, diet, longitudinal birth cohort, cardiorespiratory fitness, zinc, vitamin B6

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Significance Statement

Impulsivity is a complex trait manifesting, e.g., in our decision-making. Which food to consume is one of such choices that people make several times each day. So far, the relationship between diet and impulsivity has been mostly studied in connection with clinical manifestation of eating disorders, substance abuse, and obesity. The present report is the first longitudinal study, to our knowledge, conducted on a representative birth cohort sample of adolescents and young adults that investigates the associations between 2 impulsivity dimensions, dietary intake, and cardiorespiratory fitness. Both adaptive and maladaptive impulsivity were related to diet, while the associations were specific to the aspect of impulsivity; additionally, maladaptive impulsivity was associated with lower cardiorespiratory fitness. Higher adaptive impulsivity was associated with increased vitamin B6 levels in the dietary intake. These associations suggest that the manifestation of maladaptive impulsivity can be managed via physical activity and micronutrient supplementation.

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Introduction

Impulsivity is "a range of actions which are poorly conceived, prematurely expressed, unduly risky or inappropriate to the situation and that often result in undesirable consequences" (Daruna and Barnes, 1993). In psychiatry, impulsivity is included in diagnostic criteria for a variety of disorders, such as alcohol and substance abuse, mood and anxiety disorders, attention-deficit/hyperactivity disorder (ADHD), eating disorders, pathological gambling, and certain personality disorders (Berg et al., 2015). In psychology, impulsivity is considered the behavioral manifestation of several personality traits (Whiteside and Lynam, 2001; Zuckerman and Glicksohn, 2016). Genome-wide association studies confirm that dimensions of impulsivity form intricate relationships with psychiatric endophenotypes and show genetic overlap with ADHD and substance use disorders (Sanchez-Roige et al., 2019). A variety of distinct aspects of impulsivity have been proposed and studied, especially in clinical contexts. In the current study, however, we follow the concept of Dickman (1990) and Hans Eysenck (Eysenck, 2004) by parsing impulsivity into dysfunctional and functional dimensions. The social and personal consequences of the dysfunctional impulsive actions are usually negative, whereas manifestations of functional impulsivity are mostly beneficial. Rapid, error-prone information processing lies at the core of both types of impulsivities, and an individual's other personality traits determine the optimality of the outcomes (Dickman, 1990). The 2 types of impulsivities were measured with the original Adaptive and maladaptive impulsivity scale (AMIS) that extends the functional vs dysfunctional impulsivity model and has been successfully used for, for example, distinguishing the impulsivity profiles by the type of traffic violations (Paaver et al., 2006). Hereafter, we refer to the dysfunctional and functional dimensions of impulsivity as maladaptive and adaptive in specific cases of the impulsivity measures obtained with the AMIS questionnaire.

The genetic architecture of impulsivity is unclear as heritability of impulsive traits (40%–60%) is order(s) of magnitude larger that has been estimated from the genotyped single nucleotide polymorphisms (<10%) (Sanchez-Roige et al., 2019). In addition to genetics, the environment also plays a role, which changes with age. In principle, personality traits are malleable and can be shaped by prolonged experience or effort (Hudson and Fraley, 2015; Hudson et al., 2020). Transition from a more regimented environment of adolescence where diet and physical activity are governed by family and school into adulthood increases the risks associated with impulsive decision-making, such as overeating or risky behaviors, and tightens a putative feedback loop between personality and environment. Food choices and levels of physical exercise are manifestations of personality and decision-making that, in turn, affect biochemistry and formation of behavioral habits. In practical terms, as both nutrition and physical exercise affect brain neurochemistry, they can be considered as auxiliary tools to pharmacological methods for controlling excessive impulsivity. However, the empirical validation of the idea in the general population is scarce (Fleig et al., 2011). Studies conducted in rats show that diets high in sugar or fat can make the animals more impulsive independently of the weight gain (Adams et al., 2015; Steele et al., 2017; Garman et al., 2021). In humans, people who consume more sugar, but not fat, were found to have a stronger preference for large rewards and a lower tolerance of the delayed rewards (Steele et al., 2021). However, laboratory findings have a limited scope, and their clinical relevance is often low. The relationship between diet and impulsivity has been studied mainly along 2 paths: overeating/unhealthy food choices and (micro) nutrient deficiencies. The associations between higher impulsivity and unhealthy nutritional choices have been found in several studies. For example, overeating and greater consumption of Western-style diet, sugar-sweetened and alcoholic beverages, snacks, and take-away food have all been linked to higher impulsivity (Jasinska et al., 2012; Lumley et al., 2016; Bénard et al., 2019).

Some studies have found an association of higher impulsivity with increased energy intake and higher body mass index (BMI) (Jasinska et al., 2012; VanderBroek-Stice et al., 2017; Bénard et al., 2019). Research along the second path tries to identify the link between the bioavailability of a particular micronutrient and impulsive behavior. Increased plasma tryptophan following breakfast was associated with changes in the individual propensity for risky decisions, and this effect was modulated by BMI (Liu et al., 2021). A study conducted on a small group of students further found that higher tryptophan intake was associated with lower scores on 2 impulsivity subscales (Javelle et al., 2021a). Additionally, several studies link vitamin D deficiency with the increased propensity to act impulsively (Grudet et al., 2014; Wrzosek et al., 2018; Todisco et al., 2020).

Cardiorespiratory or aerobic fitness is a category of physical fitness that refers to the ability of circulatory and respiratory systems to supply skeletal muscles with the oxygen for energy generation during physical activity (Raghuveer et al., 2020). The role of physical exercise on impulsivity and cognitive control is primarily researched in connection with ADHD. For example, cardiorespiratory fitness was associated positively with attentional control in preadolescent children (Brassell et al., 2017) and negatively with impulsivity scores in male college students (Jeoung, 2014). The causal link between daily physical exercise and reduced impulsivity was also shown in several pilot studies (Smith et al., 2013; Choi et al., 2015). Whether a strong cardiorespiratory fitness prevents the expression of dysfunctional impulsivity in adults remains an open question; however, following a repetitive physical exercise regimen seems antithetical to impulsive actions.

During literature research, we found that most of the identified studies were cross-sectional in design and conducted on small samples, frequently on university students or children. Food habits and preferences were usually assessed by some type of survey rather than asking participants to keep diaries of the actual daily food intake. We identified 1 representative longitudinal cohort study that was part of the French NutriNet-Santé project conducted on a large sample of adult volunteers (Bénard et al., 2019). Dietary records in NutriNet-Santé study were collected every year; however, impulsivity was measured only once in older participants (average age 50 years), and micronutrient levels were not calculated from the dietary records.

Aims of the Study

We aimed to ascertain a possible longitudinal association between adaptive and maladaptive impulsivity dimensions and dietary intake. We expected that such associations would not be strong, but possible, as certain types of eating disorders and food choices have been previously associated with impulsivity. In particular, based on previous research, we expected that high maladaptive impulsivity would be associated with increased BMI and reduced cardiorespiratory fitness because the latter was predictive of symptoms of attention-deficit hyperactivity disorder at a young age in this sample (Muntaner-Mas et al., 2021). A primary role of many vitamins and metal ions is to serve as cofactors in neurotransmitter synthesis or ion channel gating, respectively, with implications particularly to both fast inhibitory and excitatory neurotransmission. Therefore, given a large sample size, we expected to find several associations with impulsivity. Because any associations between food choice and impulsivity could be bidirectional and the nutrients were calculated from the complete meals, the more parsimonious approach was to predict each impulsivity dimension in turn from the nutrients. To our knowledge, our study is the first to have such detailed nutrient categories, especially micronutrients, being longitudinal in design and simultaneously controlling for the other impulsivity dimension and fitness covariates.

METHODS AND MATERIALS

Participants and Data

Study Design and Participants—The sample included 2 birth cohorts of the longitudinal Estonian Children Personality, Behavior, and Health Study. The rationale and procedure for the original sample formation have been described in detail elsewhere (Harro et al., 2001). In brief, all schools of Tartu County, Estonia, that agreed to participate (54 of the total of 56) were included in the sampling, and 25 schools were selected to sample at least 1000 participants in total. All children from grades 3 (younger birth cohort, aged 9 years) and grades 9 (older birth cohort, aged 15 years) were invited to participate. Follow-up studies included in this paper took place in 3 waves at ages: 15 years (n = 483), 18 years (n = 454), and 25 years (n = 440) for the younger birth cohort and at ages 18 years (n = 461), 25 years (n = 541), and 33 years (n = 504) for the older birth cohort. The first proper impulsivity data were collected in the year 2001 for the older and 2004 for the younger cohort. Data were collected during a laboratory visit unless indicated otherwise. Written informed consent was obtained from the participants and from their parents if the participants were minors. The study was approved by the Ethics Review Committee on Human Research of the University of Tartu (license nos. 49/30, 151/11, 197T-14, and 235/M–20) and was conducted in accordance with the Declaration of Helsinki.

Impulsivity—Impulsivity was self-reported by filling out the AMIS questionnaire (Paaver et al., 2006). AMIS is a Likert-type questionnaire comprised of 24 five-choice items developed based on Dickman's concept of functional and dysfunctional impulsivity (Dickman, 1990). The example items for the maladaptive subscale are "I often immediately blurt out the first thing on my mind" and "Sometimes I cannot control my appetite." The example items for the adaptive subscale are "I like to be where the action is" and "I can make quick decisions even in unexpected situations." Response choice frequencies for AMIS items are provided in supplementary Figures 3 and 4. The full AMIS questionnaire and its scoring key are provided in supplementary Table 2.

Dietary Intake—The participants were asked to complete 48-hour (years 2001, 2004, and 2007) or 72-hour (years 2008 and 2014) food diaries at home during the days before the study day. On the study day, a face-to-face interview, using pictures of portion sizes (Haapa et al., 1985), was conducted to validate the information in the food diary as well as to specify intake that was not recorded. Food intake over several days was averaged to calculate the daily food intake. This food intake was then converted into composing micro- and macronutrients according to 2 reference sources of food composition: the Finnish Micro-Nutrica Nutritional Analysis program (Estonian version 2.0, Tallinn University of Technology, Food Processing Institute, Estonia) and the Estonian NutriData food consumption database (versions 4.0–7.0, National Institute for Health Development, Estonia) (Joost et al., 2019). The following macro- and micronutrients were included in the study: carbohydrates, lipids, proteins, meat, fish, eggs, dairy, cereal products, sugar and sweets, vegetables, fruits and berries, pure alcohol (all in grams per day); vitamins B1, B2, B3 (niacin), B6, C, E; calcium, iron, magnesium, manganese, phosphorus, potassium, sodium, zinc (all in milligrams per day); vitamins A (retinol), B12, D; folate, iodine, selenium (all in micrograms per day). Overall daily energy intake in kilocalories per day was also calculated.

Other Covariates—BMI was calculated as weight/height squared (kg/m^2). Cardiorespiratory fitness was determined using a cycle-ergometer (Tunturi T8, Tunturi New Fitness B.V., Finland) test with progressively increasing workload until exhaustion and was defined as maximal power output calculated per kilogram of body weight (MPO/kg bwt). In males, the initial workload was set at 50 W and increased by 50 W every 3 minutes until exhaustion. The respective workload parameters were set to 40 W in females. Criteria for exhaustion were a heart rate >185 bpm, failure to maintain pedaling frequency of at least 30 rpm, or a subjective judgment by the experimenter that the individual could no longer continue, even after encouragement (see Lätt et al., 2018 for more details). Venous blood samples (4.5 mL) were obtained after a fast of 8–12 hours by antecubital venipuncture into vacuum tubes (Vacutainer) containing 0.054 mL K3 Ethylenediaminetetraacetic acid (EDTA) as an anticoagulant. The samples were immediately centrifugated for 10 minutes, with 800 rpm, at room temperature obtaining platelet-rich plasma. Blood samples were then analyzed in a certified clinical laboratory. Insulin resistance was estimated using the homeostatic model assessment index, which was calculated as fasting glucose (mmol/l) × fasting insulin (mU/L)/22.5 (Matthews et al., 1985). Cholesterol, High-density lipoprotein (HDL) cholesterol,

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and Low-density lipoprotein (LDL) cholesterol were measured in mmol per liter except for the year 1998, where Low-density lipoprotein cholesterol was not measured but calculated based on the Friedewald formula (Winocour et al., 1989). Distributions of dietary and physiological variables used in the study are given in supplementary Figures 1 and 2. Supplementary Table 1 provides a descriptive summary of these variables stratified by age.

Outline of Data Analysis—The main steps of data analysis are depicted in Figure 1. Data validation and multiple imputation of missing data were followed by 2 streams of analysis. The main goal of the analysis was to find the best-fitting linear mixed models exploring associations of nutritional and physiological variables with 2 types of impulsivities. The secondary stream analyzed the psychometric performance of AMIS questionnaire and concluded with calculation of the latent impulsivity scores, which in turn were used to test the sensitivity of the best-fitting linear mixed models to a different method of calculating impulsivity scores.

Data Preprocessing—There were 2 main types of data missingness: all data for a survey wave were missing (attrition), or some indicators had missing data within a successful data collection wave. Additionally, in the older cohort at age 18, there were 3 missing items from the impulsivity questionnaire for all participants (items 6, 20, and 22) because AMIS was not fully developed at the time. We used multiple imputation of the missing data within successful data collection waves because it is the best way to produce unbiased statistical estimates (Figure 1). Imputation of the missing data also preserves the same number of observations, which allows the comparison of model fit scores between statistical models with different covariate

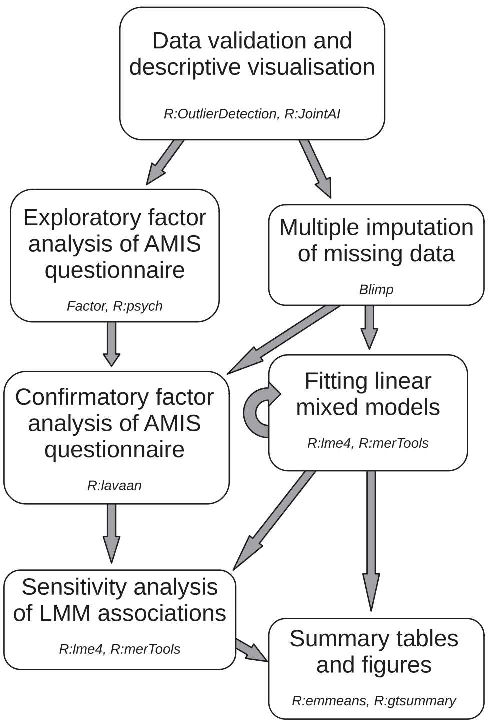

Figure 1. Flowchart of data analysis. Arrows indicate the direction of data analytic steps. Main computer software packages used to perform each analytic step are written in italic. R packages are prefixed with "R:".

structures. The missingness on different indicators varied between 0.58% and 33%. A multiple imputation of 100 plausible values was performed separately for each cohort in *Blimp* software (ver. 2.2) using the method of chained equations (Enders et al., 2018). AMIS items and dietary intake indicators were imputed in independent blocks, where age, sex, daily energy intake, cardiorespiratory fitness, and BMI were used as shared covariates between the 2 blocks.

The nominal rather than biological age of each survey wave (possible values 15, 18, 25, and 33 years) was used in statistical modeling to simplify the interpretation and visualization of the results. The age was centered at 18 years to join the data from 2 cohorts along the same time scale. All measures except for age and sex were standardized to Z-scores within each cohort and then merged. Sex was deviation coded so that the main effects in regression models would be sex neutral.

Statistical Analysis

Factor Analysis of AMIS Questionnaire—The analysis started with the psychometric re-validation of the AMIS questionnaire in this longitudinal, birth cohort representative sample. Factor analysis of AMIS items was performed on a polychoric correlation matrix using *Factor* software (Universitat Rovira i Virgili, Spain) (Lorenzo-Seva and Van Ginkel, 2016). The optimal number of common factors in the questionnaire was selected by the Hull method (Lorenzo-Seva et al., 2011). Robust diagonally weighted least-squares estimation with oblique promin rotation was used to fit the data. Missing values were imputed by a hot deck multiple imputation method offered by the *Factor* software. Factor loadings for the best-fitting 2-factor solution are provided in supplementary Table 3. Because the eighth item showed only weak loadings on either factor, it was excluded from the computation of the composite scores.

Latent Scores—A 2-factor exploratory factor analysis (EFA) was performed in *R* (R Core Team, 2022) with \`fa\` command from the *psych* package (Revelle, 2022) using weighted least-squares estimation and oblique rotation method *geominQ*. Following EFA, a model for the confirmatory factor analysis (CFA) was specified. For each factor (representing adaptive and maladaptive impulsivity), the loading magnitude was fixed for 1 item with the highest loading on that factor in EFA. Other factor loadings were freely estimated, and factor cross-loadings were permitted. This approach allowed to fit a flexible model appropriate for longitudinal data while preserving the same structure between fits on different imputed datasets. CFA was performed with *lavaan* package (Rosseel, 2012) using a diagonally weighted least-squares estimator and robust standard errors. Estimated subject scores on the 2 latent factors were computed using the Empirical Bayes Modal approach and used as substitutes for composite sum scores in regression analysis.

Linear Mixed Effects Models—Longitudinal measures of impulsivity, dietary intake, and physiological covariates were clustered within individuals; therefore, these data were modeled by a linear mixed effects approach (LMM) in *R* to account for the correlations between repeated measurements within a participant. Each individual was represented by a random intercept and, additionally, by a random age-dependent slope in some of the models. Unstructured variance-covariance matrix was specified for random effects. The maximum likelihood method was

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used to find the best-fitting model, whereas final model parameters were estimated by the restricted maximum likelihood. Models were fitted with the *lme4* package (Bates et al., 2015), which was extended for analysis of multiply imputed data with *merTools* package (Knowles and Frederick, 2020).

We modeled adaptive and maladaptive impulsivity scores separately and used 3 approaches to model fitting. Initially, the composite adaptive and maladaptive impulsivity scores were modeled in turn by including all nutrients and other covariates from which the best-fitting models were identified. The covariates with the weakest contribution to the model were removed in succession, while the model's fit was measured by the Akaike information criterion. The final model for each type of impulsivity had the lowest Akaike information criterion score and was adjusted for all significant covariates. Such an approach was preferred to the fully saturated model, as the number of covariates was rather large and the dietary intake data were inherently collinear. The fixed effects that defined each best-fitting model are provided in the left column of Tables 2 and 3. Additionally, sensitivity analyses were performed to test the strength of found associations against different model specifications.

Two more model types were tried: (1) the association between each dietary/physiological covariate and impulsivity was tested without the conditional adjustment on other covariates except for age and sex in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology guidelines (Elm et al., 2007); and (2) the best-fitting models were refitted with the same covariates, but composite impulsivity scores were substituted with the respective latent factor scores. Conceptually, a latent factor score is a score that would have been observed for a person if it had been possible to directly measure the factor. Latent factor scores weigh each item proportionally according to its loading on a common factor and therefore naturally assign low weights to items with little contribution to the latent factor.

All models were fit on 100 multiply imputed datasets. Parameter estimates from each imputed dataset were combined using Rubin's rules. Finally, the power analysis of fixed regression coefficients from the best-fitting LMMs was conducted with *simr* package (Green and MacLeod, 2016) using the parametric bootstrap test with 1000 simulations.

RESULTS

The Impulsivity Construct

Good psychometric properties of AMIS were confirmed by EFA. A 2-factor solution was the best fitting, and all items except the eighth showed significant loadings on their structural factor (supplementary Table 2). The eighth item was only weakly associated with either of the latent factors and therefore was excluded from the calculation of composite scores. The psychometric properties of AMIS were good: standardized Cronbach's alpha = .85, generalized H construct reliability indices were 0.91 (95% CI = 0.897 to 0.913) for maladaptive and 0.90 (95% CI = 0.894 to 0.908) for adaptive impulsivity factors, respectively. The 2 common factors accounted for 64.4% of the observed variance among AMIS items.

Besides the unweighted composite impulsivity scores, the exploratory CFA approach was used to compute latent factor scores that weigh each item's contribution according to its

Table 1. Descriptive Summary of the Variables Used in the Best Fitting Linear Mixed Effects Conditioned on Age

Variable	15 y, n = 483[a]	18 y, n = 915[a]	25 y, n = 981[a]	33 y, n = 504[a]	P value[b]
Sex					.63
Female	261 (54%)	515 (56%)	556 (57%)	293 (58%)	
Male	222 (46%)	400 (44%)	425 (43%)	211 (42%)	
Age, y	15.3 (15.0–15.6)	18.3 (17.9–18.7)	25.3 (24.9–25.6)	33.5 (33.1–33.9)	<.001
Adaptive impulsivity scale, units	41 (36–46)	41 (35–46)	39 (34–44)	37 (31–43)	<.001
Missing	3	462	43	2	
Maladaptive impulsivity scale, units	34 (29–38)	33 (27–38)	30 (25–35)	28 (24–34)	<.001
Missing	3	462	43	2	
Maximum power output, per kg bwt	2.69 (2.27–3.32)	2.39 (2.03–2.99)	2.62 (2.16–3.15)	2.43 (2.09–2.98)	<.001
Missing	4	84	97	57	
Pure alcohol, g	0 (0–0)	0 (0–0)	0 (0–7)	0 (0–6)	<.001
Missing	5	33	43	17	
Vegetables, g	71 (38–115)	91 (47–150)	107 (60–173)	118 (72–184)	<.001
Missing	5	33	43	17	
Cereal products, g	205 (132–286)	212 (139–324)	150 (101–220)	121 (82–164)	<.001
Missing	5	33	43	17	
Fish, g	0 (0–0)	0 (0–0)	0 (0–36)	0 (0–42)	<.001
Missing	5	33	43	17	
Sodium, mg	2448 (1812–3467)	2696 (1971–3801)	2085 (1500–2968)	2066 (1464–2954)	<.001
Missing	5	33	43	17	
Zinc, mg	9.4 (7.0–12.4)	7.4 (4.1–11.4)	9.4 (7.4–12.4)	10.4 (7.9–15.1)	<.001
Missing	5	33	43	17	
Selenium, µg	61 (44–81)	66 (49–93)	56 (42–74)	57 (42–77)	<.001
Missing	5	33	43	17	
Vitamin B6, mg	1.50 (1.12–2.08)	1.53 (1.13–2.11)	1.30 (1.00–1.80)	1.30 (1.00–1.80)	<.001
Missing	5	33	43	17	

A similar summary for all variables used in the study is provided in supplementary Table 1.
aStatistics presented: n (%) for categorical variables; median (interquartile range) for numerical variables.
bStatistical tests performed: chi-square test of independence for categorical variables; Kruskal-Wallis rank-sum test for continuous variables

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Table 2. Predictors of Maladaptive Impulsivity: Estimated Standardized Regression Coefficients and Their 95% Cis for Maladaptive Impulsivity Score as the Outcome Variable

	Unweighted composite scores: best fitting model	Unweighted composite scores: models adjusted for sex and age[a]	Latent factor scores: adjusted model[b]
Age centered at 18 y	−0.029***	−0.042***	−0.025***
	(−0.035; −0.023)	(−0.047; −0.037)	(−0.031; −0.020)
Sex: (female—male)	0.169**	0.160**	0.181***
	(0.053; 0.285)	(0.065; 0.256)	(0.075; 0.287)
Adaptive impulsivity score	0.162***	0.160***	−0.135***
	(0.123; 0.201)	(0.121; 0.199)	(−0.181; −0.089)
Maximum power output	−0.072**	−0.078***	−0.057**
	(−0.116; −0.028)	(−0.123; −0.034)	(−0.097; −0.017)
Zinc	−0.103***	−0.042*	−0.094***
	(−0.148; −0.059)	(−0.078; −0.006)	(−0.134; −0.053)
Selenium	0.066**	0.016	0.050*
	(0.018; 0.114)	(−0.020; 0.051)	(0.006; 0.094)
Sodium	0.060**	0.035	0.056**
	(0.016; 0.104)	(−0.001; 0.071)	(0.016; 0.096)
Fish	−0.047**	−0.029	−0.042**
	(−0.080; −0.014)	(−0.061; 0.003)	(−0.072; −0.012)
Vegetables	−0.039*	−0.036*	−0.039**
	(−0.072; −0.007)	(−0.068; −0.004)	(−0.068; −0.010)
Alcohol	0.036*	0.039*	0.014
	(0.004; 0.067)	(0.007; 0.071)	(−0.015; 0.043)
Sodium × sex: (female—male)	0.091**	0.102**	0.077*
	(0.023; 0.160)	(0.032; 0.172)	(0.014; 0.141)
n	2883	2883	2883

Abbreviation: CI, confidence interval.
***P < .001; **P < .01; *P < .05. Regression coefficients are standardized. 95% CIs are given in parentheses.
aThese models included sex, age, and the variable in the respective row.
bThe model includes the same variables as the best-fitting model on the left.

Table 3. Predictors of Adaptive Impulsivity: Estimated Standardized Regression Coefficients and Their 95% CIs for Adaptive Impulsivity Score as the Outcome Variable

	Unweighted composite scores: best-fitting model	Unweighted composite scores: models adjusted for sex and age[a]	Latent factor scores: adjusted model[b]
Age centered at 18 y	−0.021***	−0.023***	−0.036***
	(−0.027; −0.015)	(−0.028; −0.018)	(−0.041; −0.031)
Sex: (female—male)	−0.368***	−0.367***	−0.203***
	(−0.473; −0.262)	(−0.469; −0.265)	(−0.303; −0.104)
Maladaptive impulsivity score	0.148***	0.146***	−0.115***
	(0.113; 0.184)	(0.110; 0.182)	(−0.157; −0.072)
Zinc	0.042*	0.035*	0.008
	(0.002; 0.081)	(0.001; 0.068)	(−0.028; 0.044)
Vitamin B6	0.039*	0.048**	0.037*
	(0.006; 0.073)	(0.016; 0.080)	(0.006; 0.068)
Cereal products	−0.041*	−0.020	−0.026
	(−0.076; −0.005)	(−0.053; 0.013)	(−0.060; 0.007)
Age × sex: (female—male)	−0.013**	−0.016***	−0.013**
	(−0.023; −0.003)	(−0.026; −0.007)	(−0.021; −0.004)
n	2883	2883	2883

Abbreviation: CI, confidence interval.
***P < .001; **P < .01; *P < .05; Regression coefficients are standardized. 95% CI are given in parentheses.
aThese models included sex, age, and the variable in the respective row.
bThe model includes the same variables as the best-fitting model on the left.

loadings on the common factor. The CFA model fit was acceptable: the standardized root mean square residual was 0.073 (95% CI = 0.072 to 0.075), the comparative fit index was 0.93 (0.927 to 0.932), and the robust comparative fit index was 0.77 (0.76 to 0.78).

Predictors of Impulsivity

Descriptive summaries of the variables used as predictors of impulsivity are presented in Table 1, and the conditional associations between maladaptive impulsivity scores with covariates

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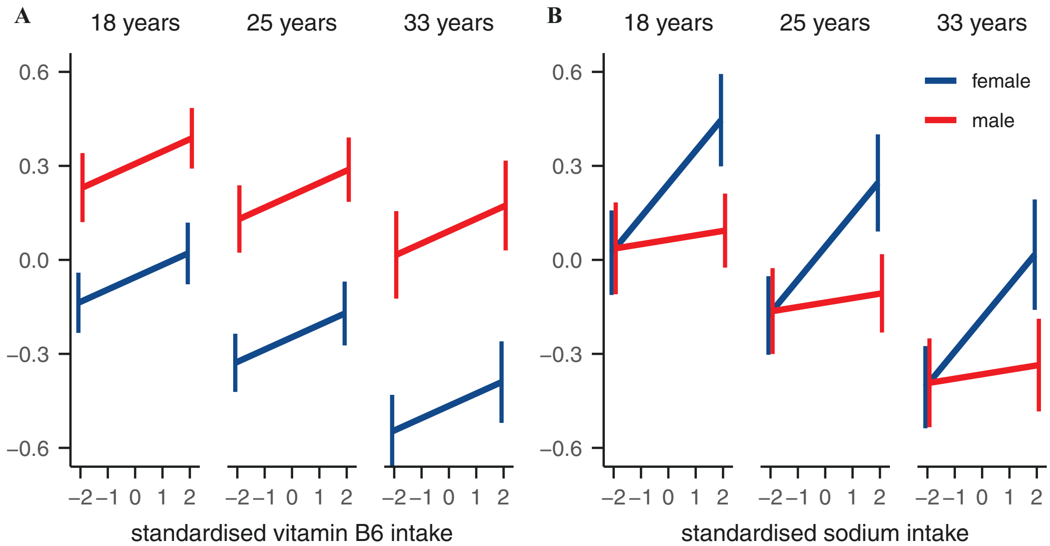

Figure 2. Predicted associations between vitamin B6, sodium, and impulsivity. Estimated standardized marginal means from the best fitting LMMs. Association between vitamin B6 and standardized adaptive impulsivity score (y-axis) conditioned on sex and age (A). Association between sodium and standardized maladaptive impulsivity score (y-axis) conditioned on sex and age (Panel B).

are provided in Table 2. The marginal coefficient of determination (R^2) for the best-fitting model was 0.11, while the conditional R^2 was 0.59. The marginal R^2 relays only the variance of the fixed effects, while the conditional R^2 accounts for both the fixed and random effects (Nakagawa et al., 2017). In the full model with latent factor scores, the respective parameters were 0.09 and 0.54. All models agreed that maladaptive impulsivity declined with age and was higher in females. Regardless of the sex, higher maladaptive impulsivity was associated with lower dietary intake of zinc, vegetables, and cardiorespiratory fitness. In contrast, the association of sodium intake with maladaptive impulsivity was stronger among females. Adjusted models additionally indicated a positive association of maladaptive impulsivity with selenium intake and a negative association between maladaptive impulsivity and fish consumption. A positive association between maladaptive impulsivity and alcohol consumption was statistically weak, and it disappeared in the model with latent factor scores.

The conditional associations between adaptive impulsivity scores with covariates are given in Table 3. The marginal R^2 for the main model was 0.10, while the conditional R^2 was 0.65. In the full model with latent factor scores, the respective parameters were 0.10 and 0.59. All models demonstrated that adaptive impulsivity declined with age and was higher in males. The age-dependent decline was steeper among females. Adaptive impulsivity was associated with fewer covariates compared with maladaptive impulsivity. All models showed a positive association of vitamin B6 intake with adaptive impulsivity. Zinc intake was also positively associated with adaptive impulsivity, but this effect disappeared in the model with latent factor scores.

Both factor analysis and LMM approaches showed that 2 impulsivity scales share some common variance as adaptive and maladaptive impulsivity scores were positively correlated. However, the latent factor scores approach to modeling reduced the magnitude of correlation between the 2 dimensions of impulsivity. Diagnostic plots of the best-fitting LMMs are provided in supplementary Figure 5. The marginal best-fitting model estimates of the associations between sodium and maladaptive impulsivity, as well as vitamin B6 and adaptive impulsivity, are illustrated in Figure 2.

As an additional check on our results, we conducted a simulation to estimate the statistical power of our best-fitting models to reject the null hypothesis. If we take the conventional benchmark for statistical power to reject the null hypothesis of 80%, then in the maladaptive impulsivity model the results for alcohol of 73.8% (95% CI = 69.7% to 77.6%) and vegetables of 75% (71% to 78.7%) were underpowered. The results for other covariates were appropriately powered. For example, for cardiorespiratory fitness, the power was 92.2% (89.5% to 94.4%) and for adaptive impulsivity, age, and zinc the power was 100% (99.3% to 100%). The predictors in the adaptive impulsivity LMM were less well powered: zinc had the highest *P* value, and this result was underpowered at 47.2% (42.8% to 51.7%). The vitamin B6 result was also underpowered at 61.6% (57.2% to 65.9%). For cereal products, the power was 62.8% (58.4% to 67.1%). The power for the interaction between age and sex was 78.2% (74.3% to 81.7%). Age, adaptive impulsivity, and sex were well-powered at 100% (99.3% to 100%).

Discussion

In the current study, the domain of impulsivity was divided into functional and dysfunctional impulsivity. It is not the most popular approach to study impulsivity, because most studies concentrate on dysfunctional impulsivity, especially in clinical settings. However, our goal was to measure everyday manifestations of impulsivity rather than concentrate on clinical pathology. Such an approach is rooted in the understanding that impulsivity is a multifaceted phenomenon that spans the continuum from calculated risk-taking and adventurousness to pathological, harmful to the subject manifestations of impulsiveness (Evenden, 1999; Whiteside and Lynam, 2001; Strickland and Johnson, 2021). First, we re-validated the impulsivity questionnaire (AMIS) on the longitudinal sample. A brief history of the AMIS is required here to explain its relationship to Dickman's concepts of functional and dysfunctional impulsivity. In the process of adaptation of the

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Estonian version of Dickman's scale, it was found that the items from the functional impulsivity subscale loaded on the same factor as personality Revised NEO Personality Inventory (NEO-PI-R) (Costa and McCrae, 2008). Extraversion scale items and the items of dysfunctional impulsivity subscale loaded on the same factor as NEO-PI-R Neuroticism scale items (Pulver, A., unpublished data). Based on factor structure, items from the Estonian NEO-PI-R items pool were added to Dickman's subscales. Conceptually, impulsivity is a manifestation of cognitive, emotional, and behavioral aspects of personality traits (Whiteside and Lynam, 2001; Fischer et al., 2008), and it is reasonable to extend Dickman's functional and dysfunctional impulsivity concept to a more dispositional personality construct. Because AMIS combines items from the original Dickman's impulsivity scale with NEO-PI-R items, the 2 primary dimensions of the questionnaire were named adaptive and maladaptive impulsivity to avoid confusion. Previously, AMIS scores were used to investigate driving and substance abuse: adaptive and maladaptive impulsivity scores were associated with risky driving and alcohol abuse in nationally representative samples of car drivers (Eensoo et al., 2004; Paaver et al., 2006; Luht et al., 2019) and in a cross-sectional analysis on the ECPBHS (Laas et al., 2010).

Both dimensions of impulsivity declined with age and showed sex dependence: adaptive impulsivity scores were higher among males, and maladaptive impulsivity scores were higher among females. AMIS impulsivity scales were conditionally correlated with a magnitude of approximately 0.2, which agrees well with the magnitude (0.23) of correlation between functional and dysfunctional scales reported by Dickman (1990) and other authors (Chico et al., 2003; Miller et al., 2004). Maladaptive impulsivity was slightly better explained by the included covariates than adaptive impulsivity, because marginal R^2 coefficients were 0.11 and 0.10 for the respective best-fitting models. Inclusion of the individual-specific variance in LMMs was well justified, because conditional R^2 coefficients indicated that best-fitting models accounted for over 50% of the total variance. These results show that, as expected, nutritional and selected physiological data can account for only approximately 10% of impulsivity-related variance. Many other variables with potential explanatory power, such as genetic variants or environmental factors of other types, were not included in the present analysis. However, due to their relative stability, these unaccounted variables manifested themselves via high individual-specific variance, as shown by conditional R^2.

All 3 modeling approaches indicated a negative relationship between maladaptive impulsivity and cardiorespiratory fitness, the intake of zinc and vegetables, and positive association with sodium intake in females. Vitamin B6 intake was positively associated with adaptive impulsivity. To our knowledge, the current study of the associations between impulsivity and dietary intake is the first extensive, longitudinal investigation with 2 waves of follow-up and a nationally representative sample. Therefore, obtaining similar results with the composite sum of item scores and latent factor scores approaches provides a good confidence boost to the overall validity of the associations.

We found that associations between impulsivity and dietary intake were more numerous and potent for the maladaptive scale, measuring a more personally harmful dimension of impulsivity. Among the nutrients, zinc intake was associated with both dimensions of impulsivity in the best-fitting models of composite scores (negatively with maladaptive and positively with adaptive impulsivity), while selenium intake was positively associated with maladaptive impulsivity in adjusted models. However, association of zinc with adaptive impulsivity was weaker and did not persist in the latent factor scores model. Adjusted models also showed a significantly reduced fish intake and higher alcohol consumption in individuals with high maladaptive impulsivity scores. Hence, these associations became significant only conditional on adjustment for other nutrients, probably because both food categories are not consumed every day, and the statistical relationship was supported by fewer observations. The direction of association with alcohol consumption is well supported in the literature (Dick et al., 2010). Fish is the primary source of essential fatty acids. Dietary supplementation with essential fatty acids is advocated as a treatment of ADHD and hostile behavior (Garland and Hallahan, 2006). Overall, the pattern of associations between macronutrients and maladaptive impulsivity agrees with common sense and the results from a recent French NutriNet-Santé study (Bénard et al., 2019). In contrast to maladaptive impulsivity, the model of adaptive impulsivity showed fewer, statistically weaker associations with nutrients. The only positive association that all 3 modeling approaches agreed on was with vitamin B6. This possibly means that the adaptive impulsivity dimension is less related to specific, especially unhealthy, eating habits.

A notable non-association was BMI. The association between impulsivity and BMI in the literature appears to be relatively weak and scale dependent (Meule and Platte, 2015; Emery and Levine, 2017). Most participants in our study were of normal weight, which likely reduced the range of the possible association between impulsivity and BMI. Such association is likely more pronounced on the right tail for both dimensions. Of the significant associations, we would like to highlight the strong association between lower dietary zinc intake and higher maladaptive impulsivity scores. Zinc is an essential trace mineral vital for neurotransmitter synthesis (Robberecht et al., 2020). Vesicular zinc is released into the synaptic cleft coincidentally with glutamate and acts as a modulator of glutamatergic neurotransmission, primarily via inhibition of N-methyl-D-aspartate (NMDA) receptors (McAllister and Dyck, 2017). Low zinc levels have been studied as a potential causative factor in ADHD symptomatology. The current consensus seems to be, however, that a Western diet provides adequate levels of dietary zinc, and additional zinc supplementation beyond cases of substantial zinc deficiency does not protect against ADHD (Arnold et al., 2011; Robberecht et al., 2020). Impulsivity is the core component of ADHD, and the possible role of zinc in the genesis of impulsivity requires further research. Additionally, low dietary zinc intake and genetic dysregulation of zinc homeostasis are linked to metabolic abnormalities and diabetes (Fukunaka and Fujitani, 2018). Similarly to zinc, vitamin B6 is also an essential co-factor in many enzymatic reactions (Stover and Field, 2015), and its association with adaptive impulsivity suggests that vitamin B6 affects decision-making. Interestingly, a positive association between schizophrenia polygenic score and vitamin B6 intake was found in UK Biobank data (Hunjan et al., 2021).

Cardiorespiratory fitness exhibited a negative association with maladaptive impulsivity. As mentioned above, several studies in children have been dedicated to studying impulsivity indirectly via its inclusion in the definition of ADHD. Besides the studies mentioned in the introduction, a previous study of the ECPBHS participants indicated that being unfit in childhood (at age 9) increases the likelihood of exhibiting ADHD symptoms 6 years later in adolescence, adjusted for baseline ADHD symptoms and BMI (Muntaner-Mas et al., 2021). Nevertheless, dedicated studies, especially on the non-clinical adult samples, remain scarce. In the few identified studies, cardiorespiratory fitness was positively associated with performance on several cognitive tasks in young

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adult women (Scott et al., 2016) and lower interference in the Stroop test in young adult men (Ludyga et al., 2019). A sex-linked positive association in males only was found between the higher cardiorespiratory fitness and the performance in sustained attention tasks (Wade et al., 2020). A recent study on German adults found that all 3 subscales of the Three-Factor Impulsivity scale were negatively correlated with the duration of weekly physical exercise (Javelle et al., 2021b). However, the current longitudinal study is the first to our knowledge to report the negative association between trait impulsivity and fitness levels that persists throughout adolescence and young adulthood.

Impulsivity is widely used as a diagnostic criterion in clinical practice and to describe various forms of suboptimal decision making. It has been even claimed that "after subjective distress, impulsivity may be the most common diagnostic criteria in the fourth version of the Diagnostic and Statistical Manual for Mental Disorders" (Whiteside and Lynam, 2001). Such ubiquity of impulsivity in psychopathology requires a more critical look at the concept of impulsivity itself and its measurement, because we are very likely dealing with a multidimensional concept. For example, the best-known modern scale of impulsivity (Urgency, Premeditation, Perseverance, Sensation Seeking Impulsive Behaviour Scale) divides impulsivity into at least 4 dimensions: urgency, (lack of) premeditation, (lack of) perseverance, and sensation-seeking (Whiteside and Lynam, 2001; Rochat et al., 2018). We used a more straightforward approach of dividing impulsivity into adaptive and maladaptive scales, which, probably, does not fully represent the interplay between impulsivity dimensions and diet. However, the specificity of higher alcohol and lower fish/vegetable intake associations with the more harmful dimension of maladaptive impulsivity agrees well with the existing clinical and observational knowledge. Such observations give us confidence that novel associations obtained with zinc and vitamin B6 are also relevant in explaining the genesis of impulsive behavior. This assertion may seem counter-intuitive, because it would be more natural to assume that the impulsive disposition leads to certain nutritional outcomes; however, causal inference in nutritional epidemiology is difficult (Ohukainen et al., 2022). For example, based on data from genome-wide association studies, it was shown that ADHD symptoms and loneliness are among phenotypes related to obesity (García-Marín et al., 2021). Our results show a possible feedback loop: food preferences may affect neurochemistry and therefore regulate the frequency of impulsive actions and thoughts. Micronutrients such as minerals and vitamins are essential factors in metabolic pathways, and their levels should be assessed more widely in studies of mental health and nutrition.

Our study has several limitations. It was purely observational and did not measure the physiological concentrations of micronutrients. The estimation of nutrients from the observational data is imprecise and is affected by longitudinal changes in the measurement instruments, dietary habits, and food technology (Vaask et al., 2004). Only few studies have researched the validity of measuring the dietary intake from food diaries against a direct observation (Karvetti and Knuts, 1992; Gariballa and Forster, 2008). Both studies agreed that food diaries provide a valid method of measuring dietary intake across ages. The participants' food intake was measured for only a few days, and there were gaps of 3 to 8 years between subsequent study waves. Between follow-up studies, Estonian society was changing rapidly, including in its dietary behavior: BMI and obesity rates increased over the period of 2006–2018 (Reile et al., 2020). The association of adaptive impulsivity with the predictors used in our models was relatively weak, and the effect sizes were statistically underpowered. On the other hand, a psychometrically sound instrument was used to measure both dimensions of impulsivity, and the best predictors of maladaptive impulsivity were adequately powered. It is also the first study on the representative national sample that concurrently tracks the longitudinal association between impulsivity and dietary intake. Several biobanks in European countries have been collecting dietary records, but most of them do not collect a battery of psychometrically validated scales to measure different psychological constructs. The Estonian population is quite homogeneous genetically, and its dietary habits have changed in the last 30 years, which suggests that these results may not generalize well to other populations. The study is ongoing, and further updates on the topic are forthcoming. Because elevated impulsivity is characteristic of several psychiatric disorders, our study may have some clinical relevance. Zinc can be provided as an adjunct treatment to psychiatric patients with symptoms of impulsivity and poor self-control. Although to date there is no clear evidence of the utility of such treatment, there nevertheless might exist a small positive effect on treatment outcomes, and even the smallest clinical effects accumulate over time and improve treatment prognosis.

The present report is the first longitudinal study, to our knowledge, of such breadth to investigate the associations between the 2 impulsivity dimensions of dietary intake and cardiorespiratory fitness. It confirmed the heterogeneous nature of impulsivity. The dimension of maladaptive impulsivity was reflected in dietary choices and fitness levels. Furthermore, the negative association of zinc intake with maladaptive impulsivity as well as positive association of vitamin B6 intake with adaptive impulsivity are novel findings.

Supplementary Materials

Supplementary data are available at *International Journal of Neuropsychopharmacology (IJNPPY)* online.

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Availability of Data and Materials

All data analysis scripts and results files are available for review. The analysis scripts are available in the Zenodo repository (https://zenodo.org/record/4543947). The data files are available upon reasonable request from the corresponding author.

References

Adams WK, Sussman JL, Kaur S, D'souza AM, Kieffer TJ, Winstanley CA (2015) Long-term, calorie-restricted intake of a high-fat diet in rats reduces impulse control and ventral striatal D_2 receptor signalling – two markers of addiction vulnerability. Eur J Neurosci 42:3095–3104.

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Arnold LE, DiSilvestro RA, Bozzolo D, Bozzolo H, Crowl L, Fernandez S, Ramadan Y, Thompson S, Mo X, Abdel-Rasoul M, Joseph E (2011) Zinc for attention-deficit/hyperactivity disorder: placebo-controlled double-blind pilot trial alone and combined with amphetamine. J Child Adolesc Psychopharmacol 21:1–19.

Bates D, Mächler M, Bolker B, Walker S (2015) Fitting linear mixed-effects models using lme4. J Stat Softw 67:1–48.

Bénard M, Bellisle F, Kesse-Guyot E, Julia C, Andreeva VA, Etilé F, Reach G, Dechelotte P, Tavolacci M-P, Hercberg S, Péneau S (2019) Impulsivity is associated with food intake, snacking, and eating disorders in a general population. Am J Clin Nutr 109:117–126.

Berg JM, Latzman RD, Bliwise NG, Lilienfeld SO (2015) Parsing the heterogeneity of impulsivity: a meta-analytic review of the behavioral implications of the UPPS for psychopathology. Psychol Assess 27:1129–1146.

Brassell AA, Shoulberg EK, Pontifex MB, Smith AL, Delli Paoli AG, Hoza B (2017) Aerobic fitness and inhibition in young children: moderating roles of ADHD status and age. J Clin Child Adolesc Psychol 46:646–652.

Chico E, Tous JM, Lorenzo-Seva U, Vigil-Colet A (2003) Spanish adaptation of Dickman's Impulsivity Inventory: its relationship to Eysenck's Personality Questionnaire. Pers Indiv Diff 35:1883–1892.

Choi JW, Han DH, Kang KD, Jung HY, Renshaw PF (2015) Aerobic exercise and attention deficit hyperactivity disorder: brain research. Med Sci Sports Exerc 47:33–39.

Costa PT, McCrae RR (2008) The Revised NEO Personality Inventory (NEO-PI-R). In: The SAGE handbook of personality theory and assessment, Vol. 2. Personality measurement and testing (Boyle GJ, Matthews G, Saklofske DH, eds), pp179–198. London: SAGE Publications.

Daruna JH, Barnes PA (1993) A neurodevelopmental view of impulsivity. In: The impulsive client: theory, research, and treatment (McCown WG, Johnson JL, Shure MB, eds), pp23–37. Washington, DC: American Psychological Association.

Dick DM, Smith G, Olausson P, Mitchell SH, Leeman RF, O'Malley SS, Sher K (2010) Understanding the construct of impulsivity and its relationship to alcohol use disorders. Addict Biol 15:217–226.

Dickman SJ (1990) Functional and dysfunctional impulsivity: personality and cognitive correlates. J Pers Soc Psychol 58:95–102.

Eensoo D, Paaver M, Pulver A, Harro M, Harro J (2004) Low platelet MAO activity associated with high dysfunctional impulsivity and antisocial behavior: evidence from drunk drivers. Psychopharmacology 172:356–358.

Elm E von, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP (2007) Strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. BMJ 335:806–808.

Emery RL, Levine MD (2017) Questionnaire and behavioral task measures of impulsivity are differentially associated with body mass index: a comprehensive meta-analysis. Psychol Bull 143:868–902.

Enders CK, Keller BT, Levy R (2018) A fully conditional specification approach to multilevel imputation of categorical and continuous variables. Psychol Methods 23:298–317.

Evenden JL (1999) Varieties of impulsivity. Psychopharmacology 146:348–361.

Eysenck SBG (2004) How the impulsiveness and venturesomeness factors evolved after the measurement of psychoticism. In: On the psychobiology of personality (Stelmack RM, ed), pp 107–112. Amsterdam: Elsevier.

Fischer S, Smith G, Cyders M (2008) Another look at impulsivity: a meta-analytic review comparing specific dispositions to rash action in their relationship to bulimic symptoms. Clin Psychol Rev 28:1413–1425.

Fleig L, Lippke S, Pomp S, Schwarzer R (2011) Intervention effects of exercise self-regulation on physical exercise and eating fruits and vegetables: a longitudinal study in orthopedic and cardiac rehabilitation. Prev Med 53:182–187.

Fukunaka A, Fujitani Y (2018) Role of zinc homeostasis in the pathogenesis of diabetes and obesity. Int J Mol Sci 19:476.

García-Marín LM, Campos AI, Kho P-F, Martin NG, Cuéllar-Partida G, Rentería ME (2021) Phenome-wide screening of GWAS data reveals the complex causal architecture of obesity. Hum Genet 140:1253–1265.

Gariballa SE, Forster SJ (2008) Dietary intake of older patients in hospital and at home: the validity of patient kept food diaries. J Nutr Health Aging 12:102–106.

Garland MR, Hallahan B (2006) Essential fatty acids and their role in conditions characterised by impulsivity. Int Rev Psychiatry 18:99–105.

Garman TS, Setlow B, Orsini CA (2021) Effects of a high-fat diet on impulsive choice in rats. Physiol Behav 229:113260.

Green P, MacLeod CJ (2016) simr: an R package for power analysis of generalised linear mixed models by simulation. Methods Ecol Evol 7:493–498.

Grudet C, Malm J, Westrin A, Brundin L (2014) Suicidal patients are deficient in vitamin D, associated with a pro-inflammatory status in the blood. Psychoneuroendocrinology 50:210–219.

Haapa E, Toponen T, Pietinen P, Räsänen L (1985) Annoskuvakirja (Picture book on food portions). Helsinki, Finland: Kansanterveyslaitos.

Harro M, Eensoo D, Kiive E, Merenäkk L, Alep J, Oreland L, Harro J (2001) Platelet monoamine oxidase in healthy 9- and 15-years old children: the effect of gender, smoking and puberty. Prog Neuropsychopharmacol Biol Psychiatry 25:1497–1511.

Hudson NW, Fraley RC (2015) Volitional personality trait change: can people choose to change their personality traits? J Pers Soc Psychol 109:490–507.

Hudson NW, Fraley RC, Chopik WJ, Briley DA (2020) Change goals robustly predict trait growth: a mega-analysis of a dozen intensive longitudinal studies examining volitional change. Soc Psychol Personal Sci 11:723–732.

Hunjan AK, Hübel C, Lin Y, Eley TC, Breen G (2021) Association between polygenic propensity for psychiatric disorders and nutrient intake. Commun Biol 4:965.

Jasinska AJ, Yasuda M, Burant CF, Gregor N, Khatri S, Sweet M, Falk EB (2012) Impulsivity and inhibitory control deficits are associated with unhealthy eating in young adults. Appetite 59:738–747.

Javelle F, Li D, Zimmer P, Johnson SL (2021a) Dietary intake of tryptophan tied emotion-related impulsivity in humans. Int J Vitam Nutr Res 91:69–76.

Javelle F, Wiegand M, Joormann J, Timpano KR, Zimmer P, Johnson SL (2021b) The German Three Factor Impulsivity Index: confirmatory factor analysis and ties to demographic and health-related variables. Personal Individ Differ 171:110470.

Jeoung BJ (2014) The relationship between attention deficit hyperactivity disorder and health-related physical fitness in university students. J Exerc Rehabil 10:367–371.

Joost U, Villa I, Comasco E, Oreland L, Veidebaum T, Harro J (2019) Association between Transcription Factor AP-2B genotype,

Downloaded from https://academic.oup.com/ijnp/advance-article/doi/10.1093/ijnp/pyac052/6670849 by Tartu University (ELNET) user on 11 October 2022

obesity, insulin resistance and dietary intake in a longitudinal birth cohort study. Int J Obes 43:2095–2106.
Karvetti R-L, Knuts L-R (1992) Validity of the estimated food diary: comparison of 2-day recorded and observed food and nutrient intakes. J Am Diet Assoc 92:580–584.
Knowles JE, Frederick C (2020) merTools: tools for analyzing mixed effect regression models. https://CRAN.R-project.org/package=merTools. Accessed September 3, 2022.
Laas K, Reif A, Herterich S, Eensoo D, Lesch K-P, Harro J (2010) The effect of a functional NOS1 promoter polymorphism on impulsivity is moderated by platelet MAO activity. Psychopharmacology 209:255–261.
Lätt E, Jürimäe J, Harro J, Loit H-M, Mäestu J (2018) Low fitness is associated with metabolic risk independently of central adiposity in a cohort of 18-year-olds. Scand J Med Sci Sports 28:1084–1091.
Liu L, Artigas SO, Ulrich A, Tardu J, Mohr PNC, Wilms B, Koletzko B, Schmid SM, Park SQ (2021) Eating to dare – nutrition impacts human risky decision and related brain function. NeuroImage 233:117951.
Lorenzo-Seva U, Timmerman ME, Kiers HAL (2011) The Hull method for selecting the number of common factors. Multivar Behav Res 46:340–364.
Lorenzo-Seva U, Van Ginkel JR (2016) Multiple imputation of missing values in exploratory factor analysis of multidimensional scales: estimating latent trait scores. An Psicol 32:596.
Ludyga S, Mücke M, Colledge FMA, Pühse U, Gerber M (2019) A combined EEG-fNIRS study investigating mechanisms underlying the association between aerobic fitness and inhibitory control in young adults. Neuroscience 419:23–33.
Luht K, Tokko T, Eensoo D, Vaht M, Harro J (2019) Efficacy of intervention at traffic schools reducing impulsive action, and association with candidate gene variants. Acta Neuropsychiatr 31:159–166.
Lumley J, Stevenson RJ, Oaten MJ, Mahmut M, Yeomans MR (2016) Individual differences in impulsivity and their relationship to a Western-style diet. Personal Individ Differ 97:178–185.
Matthews DR, Hosker JP, Rudenski AS, Naylor BA, Treacher DF, Turner RC (1985) Homeostasis model assessment: insulin resistance and β-cell function from fasting plasma glucose and insulin concentrations in man. Diabetologia 28:412–419.
McAllister BB, Dyck RH (2017) Zinc transporter 3 (ZnT3) and vesicular zinc in central nervous system function. Neurosci Biobehav Rev 80:329–350.
Meule A, Platte P (2015) Facets of impulsivity interactively predict body fat and binge eating in young women. Appetite 87:352–357.
Miller E, Joseph S, Tudway J (2004) Assessing the component structure of four self-report measures of impulsivity. Personal Individ Differ 37:349–358.
Muntaner-Mas A, Ortega FB, Femia P, Kiive E, Eensoo D, Mäestu J, Franke B, Reif A, Faraone SV, Harro J (2021) Low cardiorespiratory fitness and obesity for ADHD in childhood and adolescence: a 6-year cohort study. Scand J Med Sci Sports 31:903–913.
Nakagawa S, Johnson PCD, Schielzeth H (2017) The coefficient of determination R^2 and intra-class correlation coefficient from generalized linear mixed-effects models revisited and expanded. J R Soc Interface 14:20170213.
Ohukainen P, Virtanen JK, Ala-Korpela M (2022) Vexed causal inferences in nutritional epidemiology—call for genetic help. Int J Epidemiol 51:6–15.
Paaver M, Eensoo D, Pulver A, Harro J (2006) Adaptive and maladaptive impulsivity, platelet monoamine oxidase (MAO) activity and risk-admitting in different types of risky drivers. Psychopharmacology 186:32–40.
R Core Team (2022) R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. Available at: https://www.R-project.org/.
Raghuveer G, Hartz J, Lubans DR, Takken T, Wiltz JL, Mietus-Snyder M, Perak AM, Baker-Smith C, Pietris N, Edwards NM, On behalf of the American Heart Association Young Hearts Athero, Hypertension and Obesity in the Young Committee of the Council on Lifelong Congenital Heart Disease and Heart Health in the Young (2020) Cardiorespiratory fitness in youth: an important marker of health: a scientific statement from the American Heart Association. Circulation 142:e101–e118.
Reile R, Baburin A, Veideman T, Leinsalu M (2020) Long-term trends in the body mass index and obesity risk in Estonia: an age–period–cohort approach. Int J Public Health 65:859–869.
Revelle W (2022) psych: procedures for psychological, psychometric, and personality research. Evanston, Illinois: Northwestern University. Available at: https://CRAN.R-project.org/package=psych.
Robberecht H, Verlaet AAJ, Breynaert A, De Bruyne T, Hermans N (2020) Magnesium, iron, zinc, copper and selenium status in attention-deficit/hyperactivity disorder (ADHD). Molecules 25:4440.
Rochat L, Billieux J, Gagnon J, Van der Linden M (2018) A multifactorial and integrative approach to impulsivity in neuropsychology: insights from the UPPS model of impulsivity. J Clin Exp Neuropsychol 40:45–61.
Rosseel Y (2012) lavaan: an R package for structural equation modeling. J Stat Softw 48:1–36.
Sanchez-Roige S, Fontanillas P, Elson SL, Gray JC, de Wit H, MacKillop J, Palmer AA (2019) Genome-wide association studies of impulsive personality traits (BIS-11 and UPPSP) and drug experimentation in up to 22 861 adult research participants identify loci in the *CACNA1I* and *CADM2* genes. J Neurosci 39:2662–2618.
Scott SP, De Souza MJ, Koehler K, Petkus DL, Murray-Kolb LE (2016) Cardiorespiratory fitness Is associated with better executive function in young women. Med Sci Sports Exerc 48:1994–2002.
Smith AL, Hoza B, Linnea K, McQuade JD, Tomb M, Vaughn AJ, Shoulberg EK, Hook H (2013) Pilot physical activity intervention reduces severity of ADHD symptoms in young children. J Atten Disord 17:70–82.
Steele CC, Pirkle JRA, Kirkpatrick K (2017) Diet-induced impulsivity: effects of a high-fat and a high-sugar diet on impulsive choice in rats. PLoS One 12:e0180510.
Steele CC, Steele TJ, Gwinner M, Rosenkranz SK, Kirkpatrick K (2021) The relationship between dietary fat intake, impulsive choice, and metabolic health. Appetite 165: 105292.
Stover PJ, Field MS (2015) Vitamin B-6. Adv Nutr 6:132–133.
Strickland JC, Johnson MW (2021) Rejecting impulsivity as a psychological construct: a theoretical, empirical, and sociocultural argument. Psychol Rev 128:336–361.
Todisco P, Meneguzzo P, Vogazianos P, Garolla A, Antoniades A, Tozzi F (2020) Relation between vitamin D and impulse behaviours in patients with eating disorder: a pilot observational study. Eur Eat Disord Rev 28:587–593.

Downloaded from https://academic.oup.com/ijnp/advance-article/doi/10.1093/ijnp/pyac052/6670849 by Tartu University (ELNET) user on 11 October 2022

Vaask S, Pomerleau J, Pudule I, Grinberga D, Abaravicius A, Robertson A, McKee M (2004) Comparison of the Micro-Nutrica Nutritional Analysis program and the Russian Food Composition Database using data from the Baltic Nutrition Surveys. Eur J Clin Nutr 58:573–579.

VanderBroek-Stice L, Stojek MK, Beach SRH, vanDellen MR, MacKillop J (2017) Multidimensional assessment of impulsivity in relation to obesity and food addiction. Appetite 112:59–68.

Wade NE, Kaiver CM, Wallace AL, Hatcher KF, Swartz AM, Lisdahl KM (2020) Objective aerobic fitness level and neuropsychological functioning in healthy adolescents and emerging adults: unique sex effects. Psychol Sport Exerc 51:101794.

Whiteside SP, Lynam DR (2001) The Five Factor Model and impulsivity: using a structural model of personality to understand impulsivity. Personal Individ Differ 30:669–689.

Winocour PH, Ishola M, Durrington PN (1989) Validation of the Friedewald formula for the measurement of low density lipoprotein cholesterol in insulin-dependent diabetes mellitus. Clin Chim Acta 179:79–83.

Wrzosek M, Sawicka A, Tałałaj M, Wojnar M, Nowicka G (2018) Impulsivity and vitamin D in bariatric surgery candidates. Pharmacol Rep 70:688–693.

Zuckerman M, Glicksohn J (2016) Hans Eysenck's personality model and the constructs of sensation seeking and impulsivity. Personal Individ Differ 103:48–52.

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