

EUR Research Information Portal

Brief report: Free-living physical activity levels and cognitive control in multi-problem young adults

Published in:

Frontiers in Human Neuroscience

Publication status and date:

Published: 21/10/2022

DOI (link to publisher):

[10.3389/fnhum.2022.994123](https://doi.org/10.3389/fnhum.2022.994123)

Document Version

Publisher's PDF, also known as Version of record

Document License/Available under:

CC BY

Citation for the published version (APA):

van der Sluys, M. E., Marhe, R., van der Laan, P. H., Popma, A., & Scherder, E. J. A. (2022). Brief report: Free-living physical activity levels and cognitive control in multi-problem young adults. *Frontiers in Human Neuroscience*, 16, Article 994123. <https://doi.org/10.3389/fnhum.2022.994123>

[Link to publication on the EUR Research Information Portal](#)

Terms and Conditions of Use

Except as permitted by the applicable copyright law, you may not reproduce or make this material available to any third party without the prior written permission from the copyright holder(s). Copyright law allows the following uses of this material without prior permission:

- you may download, save and print a copy of this material for your personal use only;
- you may share the EUR portal link to this material.

In case the material is published with an open access license (e.g. a Creative Commons (CC) license), other uses may be allowed. Please check the terms and conditions of the specific license.

Take-down policy

If you believe that this material infringes your copyright and/or any other intellectual property rights, you may request its removal by contacting us at the following email address: openaccess.library@eur.nl. Please provide us with all the relevant information, including the reasons why you believe any of your rights have been infringed. In case of a legitimate complaint, we will make the material inaccessible and/or remove it from the website.



OPEN ACCESS

EDITED BY

István Czigler,
Hungarian Academy of Sciences
(MTA), Hungary

REVIEWED BY

Alberto Souza Sá Filho,
Universidade Evangélica de Goiás,
Brazil
Kota Suzuki,
Shitennoji University, Japan

*CORRESPONDENCE

Maria Elise van der Sluys
m.e.vander.sluys@vu.nl

SPECIALTY SECTION

This article was submitted to
Cognitive Neuroscience,
a section of the journal
Frontiers in Human Neuroscience

RECEIVED 14 July 2022

ACCEPTED 10 October 2022

PUBLISHED 21 October 2022

CITATION

van der Sluys ME, Marhe R,
van der Laan PH, Popma A and
Scherder EJA (2022) Brief report:
Free-living physical activity levels
and cognitive control
in multi-problem young adults.
Front. Hum. Neurosci. 16:994123.
doi: 10.3389/fnhum.2022.994123

COPYRIGHT

© 2022 van der Sluys, Marhe, van der
Laan, Popma and Scherder. This is an
open-access article distributed under
the terms of the [Creative Commons
Attribution License \(CC BY\)](https://creativecommons.org/licenses/by/4.0/). The use,
distribution or reproduction in other
forums is permitted, provided the
original author(s) and the copyright
owner(s) are credited and that the
original publication in this journal is
cited, in accordance with accepted
academic practice. No use, distribution
or reproduction is permitted which
does not comply with these terms.

Brief report: Free-living physical activity levels and cognitive control in multi-problem young adults

Maria Elise van der Sluys^{1*}, Reshmi Marhe²,
Peter H. van der Laan^{3,4}, Arne Popma⁵ and
Erik J. A. Scherder¹

¹Department of Clinical, Neuro and Developmental Psychology, Vrije Universiteit Amsterdam, Amsterdam, Netherlands, ²Department of Psychology, Education and Child Studies, Erasmus University Rotterdam, Rotterdam, Netherlands, ³Department of Criminal Law and Criminology, Vrije Universiteit Amsterdam, Amsterdam, Netherlands, ⁴Netherlands Institute for the Study of Crime and Law Enforcement, Amsterdam, Netherlands, ⁵Department of Child and Adolescent Psychiatry, VU University Medical Center, Amsterdam, Netherlands

Previous studies indicate a positive association between physical activity and cognitive control in sedentary but healthy adults, yet not much is known about physical activity levels in multi-problem young adults. We examined the level of self-reported free-living physical activity (i.e., MET minutes per week) in an ecologically valid sample of young adults facing multiple problems, including unemployment, lack of education, frequent substance use, and history of delinquency. We compared cognitive control with an age- and sex-matched control sample. Additionally, the association between physical activity and cognitive control (i.e., response inhibition, error processing, interference effect) in the multi-problem group was examined. Physical activity and cognitive control were measured with the International Physical Activity Questionnaire-Long Form and three cognitive control experiments (i.e., Flanker, Go/NoGo, Stroop), respectively. With $M = 4428$ Metabolic Equivalents (METs), our multi-problem sample ($n = 63$) showed physical activity levels similar to the age- and sex-matched control sample from the general population ($n = 62$). The multi-problem young adults also showed impaired cognitive control indexed as decreased response inhibition and decreased Flanker correctness effect compared to their peers. We could not find an association between self-reported physical activity and cognitive control in the multi-problem sample. Due to the small sample size, results should be interpreted with caution. However, future dose-response studies could still use these results to further examine if within-individual increased physical activity may possibly lead to improved cognitive control in (already relatively active) multi-problem young adults.

KEYWORDS

physical activity, cognitive control, multi-problem young adults, brief report, ecologically valid sample

Introduction

Cognitive control (also called executive functioning) comprises a set of top-down processes enabling self-regulation, future- and goal-oriented behavior, and the focus of attention (Diamond, 2013). Deficits in cognitive control are found in several clinical disorders, including attention-deficit/hyperactivity disorder, autism spectrum disorder, and traumatic brain injury (Craig et al., 2016). Besides clinical disorders, there is also evidence that basic physical activity levels are associated with altered cognitive control functioning. Results from observational studies show impaired cognitive control in sedentary individuals compared to active individuals across the human lifespan (Hillman et al., 2008; Kamijo et al., 2009; Chaddock et al., 2010; Kamijo and Takeda, 2009, 2010; Bae et al., 2012; Padilla et al., 2013, 2014; Pérez et al., 2014; Verburgh et al., 2014; van der Niet et al., 2015; Baumgartner et al., 2018).

More specifically, in sedentary but otherwise healthy young adults there are indications for impaired cognitive control, reflected in a relative inability to restrain inappropriate responses (i.e., response inhibition) (Hogan et al., 2013), to adequately process errors (i.e., error processing) (Pérez et al., 2014), and to suppress an automated response in favor of a less automated response (i.e., cognitive interference) (Giles et al., 2017; Goenarjo et al., 2020). Not surprisingly, the same cognitive control deficits (i.e., impaired response inhibition, error processing, and cognitive interference) have been found in individuals displaying antisocial behavior including aggression, delinquency, and substance use (Hiatt et al., 2004; Swann et al., 2009; Zeier et al., 2012; Marhe et al., 2013; Weidacker et al., 2017; Turner et al., 2018). These similarities are exemplified in task performance on a Flanker task (a reaction-time task that is frequently used to measure error processing indices), with significantly lower Flanker accuracy in low active preadolescents ($M = 88.6$, $SD = 2.4$) compared to medium active ($M = 96.1$, $SD = 1.8$) and high active ($M = 98.4$, $SD = 0.2$) preadolescents in the general population (Zhu et al., 2022). Like low active youngsters, low Flanker accuracy is found in substance abusers ($M = 84$) vs. non-users ($M = 91$) (Marhe et al., 2013) and in multi-problem young adults ($M = 81$, $SD = 0.16$) vs. controls from the general population ($M = 87$, $SD = 0.09$) (Zijlmans et al., 2019). Although sedentary and problem populations show similar results on cognitive control measures, it is not yet known whether the physical activity level plays a role in the diminished cognitive control processing of multi-problem young adults.

Previous studies uncovered a positive association between physical activity and cognitive control in healthy young adults from the general population, with higher physical activity levels associated with better cognitive control (Hogan et al., 2013; Pérez et al., 2014; Giles et al., 2017; Goenarjo et al., 2020). Moreover, there is ample evidence that an increase in physical activity enhances cognitive control

(Colcombe and Kramer, 2003; Hillman et al., 2008; Smith et al., 2010; Gomez-Pinilla and Hillman, 2013; Guiney and Machado, 2013; Verburgh et al., 2014), particularly in individuals with a sedentary lifestyle (Gomez-Pinilla and Hillman, 2013; Verburgh et al., 2014). Ultimately, if physical activity can enhance cognitive control, it might help populations that are compromised in their cognitive control functioning. As multi-problem young adults are such a population, they might benefit from extra physical activity. However, as a first step, it is important to gain knowledge on the level of physical activity, i.e., the art of lifestyle, and the association with cognitive control in this group of young adults.

Physical activity has multiple associated health benefits (Paluska and Schwenk, 2000; Lubans et al., 2012; Daskalopoulou et al., 2017) including reduced risk on physical disorders (e.g., cardiovascular disease and obesity: Carnethon et al., 2003) and reduced risk on mental disorders (e.g., depression and anxiety: Kantomaa et al., 2008; Rebar et al., 2015). According to the American College and Sports Medicine (ACSM) and the World Health Organization (WHO), (young) adults should achieve at least 150 min of moderate physical activity, or 60 (ACSM) to (WHO) of vigorous-intensity physical activity per week (Riebe et al., 2018; Bull et al., 2020; World Health Organization [WHO], 2020). Most young adults from the general population do not meet these recommendations (Song et al., 2013; Marques et al., 2015). To the authors' knowledge, it is unknown if these recommendations are met by young adults facing multiple problems including a lack of daytime activities (such as work or education), low or no income, behavioral and psychological problems, frequent substance use, and a history of delinquency (Luijks et al., 2017; van Duin et al., 2017, 2018; Zijlmans et al., 2018, 2019, 2020a,b; van der Sluys et al., 2020). Previous research on physical activity levels in these or similar populations is lacking or prison-based (Fischer et al., 2012) and related research on factors associated with level of physical activity in such populations indicates mixed results. For example, having parents without a high school diploma (Singh et al., 2008) and having a low socio-economic status (SES) (Stalsberg and Pedersen, 2010) are associated with a sedentary lifestyle, yet lack of means of transportation (Spinney and Millward, 2010), e.g., due to low or no income, is associated with a more active lifestyle. Thus, more information is needed on physical activity levels in young adults displaying multiple problems (including antisocial behavior).

The current study therefore first aims to examine the self-reported free-living (i.e., habitual) physical activity in multi-problem young men aged 18–27 (Luijks et al., 2017; van Duin et al., 2017, 2018; Zijlmans et al., 2018, 2019, 2020a,b; van der Sluys et al., 2020). Due to mixed results in previous literature (Singh et al., 2008; Spinney and Millward, 2010; Stalsberg and Pedersen, 2010), it is not possible to form a concrete hypothesis on the level of physical activity. To confirm the expected impairment in cognitive control as measured

with the behavioral measures of response inhibition, error processing, and cognitive interference (Hiatt et al., 2004; Swann et al., 2009; Zeier et al., 2012; Marhe et al., 2013; Weidacker et al., 2017; Turner et al., 2018; Zijlmans et al., 2020a), we perform a supplementary analysis comparing the multi-problem young adults with age- and sex matched controls from the general population. Second, we examine if there is a possible association between free-living physical activity and cognitive control. Based on literature in healthy young adults from the general population, we expect a positive association in the multi-problem group (Hogan et al., 2013; Pérez et al., 2014; Giles et al., 2017; Goenarjo et al., 2020).

Materials and methods

Participants

Participants were 63 multi-problem young adult men aged 18–27, recruited at the start of the day treatment program *De Nieuwe Kans* (DNK; translated as “New Opportunities,” for more information on the program (see Luijckx et al., 2017; van der Sluys et al., 2020). In short, DNK offers practical support and cognitive behavioral therapy to young adult men (aged 18–27) suffering from a range of problems including low or no income, low or no education, lack of daytime activities, frequent drug use, and a criminal record. The main aim of the treatment is to increase self-sufficiency through education and employment. Fifteen participants were excluded from the analyses due to failure to complete the cognitive control measures ($n = 13$) or questionnaires ($n = 2$). Thus, the final sample of multi-problem young adults included ($n = 50$) for the comparison on cognitive control with age- and sex matched controls from the general population ($n = 62$, mean age 23.6, SD 2.7) and ($n = 48$) for the analysis on the association between physical activity and cognitive control. In addition, to confirm if our multi-problem sample suffered from more problems on various other secondary outcomes measured with questionnaires, multiple independent sample t -tests were run ($n = 61$). The multi-problem young adults experienced significantly more problems, showing less education, overall less daytime activities, overall more family problems, more impulsivity, and more years of regular cannabis use compared to the control sample (see **Supplementary Table 1**). Surprisingly, alcohol consumption was larger in the control sample, possibly because this group comprises mostly college students where high rates of (binge) drinking are associated with multiple individual and environmental changes (Krieger et al., 2018).

A priori sample size calculations indicated a required sample size of $N = 86$ for the comparison between groups on cognitive control (power = 0.80, $f^2 = 0.25$: Morgan and Lilienfeld, 2000) and $N = 92$ for the regression on physical activity and cognitive control within the multi-problem group

(power = 0.80, $f^2 = 0.15$: Cameron et al., 2015). However, due to the unforeseen closing of the day treatment program as a direct result of the COVID-19 pandemic, it was not possible to continue data collection.

Cognitive control

All cognitive control experiments (Flanker, Go/NoGo, Stroop) were self-administered with E-Prime 3.0 software (Stoet, 2017, 2010) after an explanation from a trained researcher.

Response inhibition was measured with a Go/NoGo task previously described in Luijckx et al. (2013) and Zijlmans et al. (2020a). To summarize, participants were required to press the spacebar with their left or right hand on a QWERTY-keyboard in response to a letter (Go trials) and withhold this response when the presented letter was a repetition of the previous one (NoGo trials). Stimuli were presented at 1 HZ and shown for 700 ms, followed by a blank screen for 300 ms. The total response window was set at 1000 ms (700 ms + 300 ms). A total of 817 Go and 110 NoGo trials (i.e., 12% NoGo trials) were presented in an unpredictable manner by introducing jitter in the number of intervening Go trials ($M = 7.25$, range 3–16). The task included four short rest moments (15 seconds each). Accuracy on the NoGo trials was used as measure for response inhibition with higher accuracy on the NoGo trials indicating better response inhibition.

Error processing was measured with a Flanker task previously described in Zijlmans et al. (2019). In short, participants were shown congruent and incongruent letter strings (HHHHH, SSSSS, HHS HH, SSHSS). They were required to respond to the middle letter by pressing the corresponding letter on a QWERTY-keyboard with their left or right index finger as fast and accurate as possible. The task consisted of 200 congruent and 200 incongruent trials, presented at random. Each letter string was presented for 52 ms followed by a blank screen (648 ms). The total response window was set at 700 ms (52 ms + 648 ms) followed by an inter-stimulus-interval (ISI) of 1000 ms. The task was divided into five blocks of 80 trials with a short pause in between (15 seconds rest). Total accuracy, post error slowing (post error reaction time - post correct reaction time), and correctness effect (reaction time correct trials - reaction time incorrect trials) were calculated as response measures for the Flanker task. Higher post-error slowing is interpreted as better error processing.

Lastly, interference or Stroop effect was measured with a computerized non-verbal Stroop Color-Word Test. Participants were presented with a word (red, blue, yellow, green) written in one of the same colors (red, blue, yellow, green). They were instructed to respond to the color of the ink by pressing the letters d, f, j, or k, representative of a matching color shown on screen. Participants were asked to respond as fast and accurate as possible. The trial started with a fixation cross shown

for 250 ms, followed by the colored word which was shown for 3000 ms or until the respondent responded. After that, the feedback followed (“correct,” “incorrect,” and “no response detected”) which was shown for 500 ms. During the practice trials, participants were shown a colored letter string (XXXXX) in one of the colors to practice the button press. The experiment with the colored words consisted out of two similar blocks divided by a self-paced rest period. Participants were shown a total of 192 trials, divided into 144 incongruent (different written word and color) and 48 congruent trials (same written word and color), prefaced by 40 practice trials (i.e., 30 congruent and 10 incongruent trials). The interference effect (reaction time incongruent trials - reaction time congruent trials) was calculated and used as an outcome measure. A higher score is interpreted as increased cognitive interference.

Questionnaires

All questionnaires were asked in the form of a structured interview using Castor Electronic Data Capture (IBM, 2011). Free-living physical activity was measured with the long version of the International Physical Activity Questionnaire (IPAQ; Hagströmer et al., 2006). The IPAQ is a self-report questionnaire for adults (aged 18–65) measuring the frequency, duration, and intensity of physical activity over the past 7 days. Total physical activity expressed as Metabolic Equivalents (METs) minutes per week was used as measure of physical activity level. One MET represents an activity burning 1 kcal per kilogram bodyweight per hour. MET minutes per week are calculated by multiplying weekly duration per activity (daily activity × number of days of performed activity) by the MET values corresponding to the required exertion for that specific activity (Ainsworth et al., 2000).

Because the association between physical activity and cognitive control may be influenced by body composition (Galioto Wiedemann et al., 2014) and intelligence (Hillman et al., 2005), we included Body Mass Index (BMI) and the score on a screener for low intelligence or a learning disability as control variables. BMI was measured by dividing self-reported height² by self-reported weight. BMI is an international measurement used for classifying adults based on body weight and height. Lastly, a Screener for Intelligence and Learning Disabilities (SCIL 18+; Nijman et al., 2018) was used to screen

for mild to borderline intellectual disabilities. The total score on the screener was included. A score of 19 or lower is indicative of possible intellectual disabilities.

Procedure

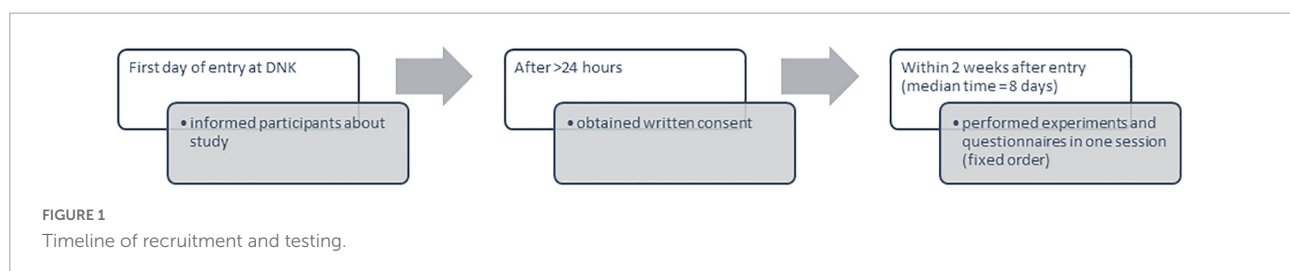
This study was approved by the Scientific and Ethical Review Board of the VU University Amsterdam (VCWE-2017-139). Participants provided written informed consent prior to study participation. A reimbursement of 10 euros was distributed for completing the questionnaires and cognitive control-tasks.

On the first day of entry at DNK, all treatment-seekers at DNK were informed about the content of the study. They were given at least 24 hours to decide about their participation. After giving written consent, participants were tested within 2 weeks after entry at DNK by trained researchers (median time between testing and entry: 8 days) at DNK. The cognitive control experiments and questionnaires were tested in the same session, starting with an explanation, then the experiments in fixed order, and ending with the questionnaires (see Figure 1). Participants were eligible if they had sufficient knowledge of the Dutch language and did not suffer from colorblindness.

Participants for the control sample were recruited through university message boards or *via* social media such as Facebook or Instagram, using snowball sampling and convenience sampling. Participants were eligible for the control sample if they were male, aged between 18 and 27, had sufficient knowledge of the Dutch language, and did not suffer from colorblindness.

Statistical analyses

IBM SPSS Statistics for Windows version 20.0 (IBM, 2011) was used to perform the statistical analyses. First, self-reported free-living physical activity was examined by reporting the continuous MET score of the IPAQ. Additionally, to examine if the multi-problem sample ($n = 50$) vs. age-sex matched controls ($n = 62$; between-group variable) showed the expected impairment on the selected measures of response inhibition, error processing, and cognitive interference (i.e., five dependent variables), a one-way multivariate analysis of variance (MANOVA) was performed. For the MANOVA, data



was bootstrapped due to non-normality of NoGo accuracy. Bonferroni correction was applied to correct for multiple testing in the univariate tests ($p = 0.01$). Lastly, within the multi-problem sample ($n = 48$), the association between free-living physical activity (i.e., MET score; dependent variable) and the selected measures of response inhibition, error processing, and cognitive interference (i.e., five predictor variables) was tested with an exploratory hierarchical linear regression analysis with two steps. The continuous score on the SCIL and BMI were entered as covariates in the first step with the cognitive control measurements added in the second step. Due to violation of the normality of residuals assumption, the log (LN) transformation of the MET score was computed and used in the regression. This solved the non-normality of the residuals. None of the other assumptions was violated. The level of significance was set at $p = 0.05$ for the linear regression.

Results

Self-reported free-living physical activity

The multi-problem young adults scored $M = 4428$ MET minutes per week (Table 1).

Cognitive control

Results from the MANOVA indicate significant cognitive control deficits in response inhibition and performance on a Flanker task in the multi-problem sample compared to the control group [$F(5, 106) = 13.81$; $p < 0.01$; partial $\eta^2 = 0.983$], specifically for NoGo accuracy [$F(1, 110) = 32.68$;

$p < 0.001$; partial $\eta^2 = 0.22$], and Flanker correctness effect [$F(1, 110) = 13.05$; $p < 0.001$; partial $\eta^2 = 0.10$]. See Table 1 for side-by-side comparison of means.

In the explorative linear analysis within the multi-problem group, we did not find the hypothesized significant association between free-living physical activity (i.e., MET minutes per week) and cognitive control (i.e., Stroop interference, Flanker total accuracy, Flanker post-error slowing, Flanker correctness effect, NoGo accuracy; Table 2). The first model containing only the covariates (SCIL, BMI) was not significant ($p = 0.849$, adj $R^2 = -0.037$), nor was the model with the added cognitive control measures ($p = 0.225$, adj $R^2 = 0.059$). Results should be interpreted with caution due to the small sample size.

Discussion

Although the level of physical activity (4428 MET) in the multi-problem young adult group was well above adult WHO recommendations (900 MET: (World Health Organization [WHO], 2020), these levels are comparable with the physical activity in the age- and sex matched control sample ($M = 4853$). Similarly, in a previous study with Ukrainian students using the same IPAQ questionnaire as the current study, total mean activity was 3560 MET (Bergier et al., 2014). This may indicate that (multi-problem) young adults are more active than previously expected based on adolescent (Song et al., 2013) and adult (Marques et al., 2015) samples not suffering from multiple problems, which mostly do not meet these recommendations. More specifically, there is a global trend related to low levels of physical activity among adolescents and (young) adults from the general population (Valle et al., 2015; Guthold et al., 2020), with physical activity levels further declining between adolescence and young adulthood (for a meta-review, see Corder et al., 2019). Less is known about individuals suffering from a range of

TABLE 1 Main outcome measures of multi-problem young adults and healthy young adults from the general population.

Variable	Multi-problem sample ($N = 50$)		Control sample ($N = 62$)		Univariate testing	Between group effect size
	M	SD	M	SD	p	Cohen's d
Stroop interference (RT incongruent—RT congruent)	75.94	64.04	61.26	46.97	0.165	0.26
Flanker total accuracy	0.81	0.16	0.86	0.08	0.030	-0.39
Flanker post-error slowing (RT post error—RT post correct)	26.03	59.58	15.50	40.34	0.269	0.20
Flanker correctness effect (RT correct—RT incorrect)*	-28.36	75.99	12.71	42.62	<0.001	-0.66
NoGo accuracy*	0.52	0.17	0.68	0.11	<0.001	-1.11
IPAQ METs	4428.74	4259.26	4853.67	3978.42		-0.10
BMI (weight in kg/height in cm^2)	22.83	4.11	23.30	3.15		-0.12
SCIL intelligence total	13.58	5.36				

IPAQ, International Physical Activity Questionnaire; MET, Metabolic Equivalents minutes per week; BMI, Body Mass Index; SCIL, Screener for Intelligence and Learning Disabilities.

Cohen's $d = ((M_{\text{multi-problem}} - M_{\text{control sample}}) / SD_{\text{pooled}})$.

* $p < 0.01$ (Bonferroni correction applied).

TABLE 2 Results of linear regression examining free-living physical activity and cognitive control in multi-problem young adults ($N = 48$).

	B	SE (B)	<i>p</i>	<i>t</i>	95% CI B	
					Lower	Upper
Model 1						
Constant	8.235	0.901	<0.001	9.140	6.420	10.050
BMI (weight in kg/height in cm ²)	−0.003	0.036	0.941	−0.075	−0.075	0.069
SCIL	−0.016	0.027	0.575	−0.565	−0.071	0.040
Model 2						
Constant	7.177	1.143	<0.001	6.281	4.867	9.486
BMI (weight in kg/height in cm ²)	0.000	0.035	0.997	−0.004	−0.071	0.071
SCIL	−0.047	0.030	0.124	−1.573	−0.107	0.013
Stroop interference (RT incongruent—RT congruent)	−0.001	0.003	0.821	−0.227	−0.006	0.005
Flanker total accuracy	1.360	1.324	0.311	1.027	−1.317	4.036
Flanker post-error slowing (RT post error—RT post correct)	0.007	0.004	0.070	1.858	−0.001	0.014
Flanker correctness effect (RT correct—RT incorrect)	0.004	0.003	0.176	1.377	−0.002	0.011
NoGo accuracy	0.593	1.027	0.567	0.577	−1.484	2.669

BMI, Body Mass Index; SCIL, Screener for Intelligence and Learning Disabilities.

(psychological, financial, and behavioral) problems such as the current multi-problem sample, although there are indications for a sedentary lifestyle in similar populations (such as having parents without a high school diploma (Singh et al., 2008), a low SES (Stalsberg and Pedersen, 2010), and having only one parent present (Junger et al., 2001). As the current results indicate high physical activity levels in multi-problem young adults, contrary to existing research, it may be worthwhile to conduct more studies in young adults displaying several problems. Possible other relevant factors to include in future studies are gender [with males being more active (Bergier et al., 2014, 2017)], lack of having a (sitting) job (Thorp et al., 2012), and place of residence (Bergier et al., 2016).

Consistent with our first hypothesis, we confirmed the cognitive control impairments in our sample of multi-problem young adult men compared to the age- and sex-matched controls from the general population (Hiatt et al., 2004; Swann et al., 2009; Zeier et al., 2012; Marhe et al., 2013; Weidacker et al., 2017; Turner et al., 2018), specifically on response inhibition and the Flanker correctness effect. We also saw a trend for accuracy on the Flanker task, however, after correcting for multiple testing, this result did not remain significant. Effect sizes (Cohen's d) were, respectively, large, small-medium, and medium-large in favor of the control group (Cohen, 1988), which is in line with meta-analytic results on cognitive control in antisocial populations where medium ($d = 0.44$; Ogilvie et al., 2011) and large ($d = 0.62$; Morgan and Lilienfeld, 2000) effect sizes were found in favor of healthy control samples. The current results are similar to other studies in populations showing multiple problems including antisocial behavior and addiction (Swann et al., 2009; Ogilvie et al., 2011; Zeier et al., 2012; Marhe et al., 2013; Weidacker et al., 2017; Turner et al., 2018). Cognitive control may be impaired due to co-existing disorders such as Attention-Deficit/Hyperactivity Disorder (ADHD) or autism spectrum disorder (Craig et al., 2016) or due to traumatic

brain injury (Schretlen and Shapiro, 2003), which may be overrepresented in our sample of multi-problem young adults (Storebø and Simonsen, 2016; Bellesi et al., 2019; Chester et al., 2022). Another possible explanation may be the relatively lower IQ in the multi-problem sample compared to their peers from the general population, as previous studies indicate a positive association between IQ and cognitive control (Zijlmans et al., 2019).

However, we could not find support for our second hypothesis, as our results do not indicate a positive association between physical activity and cognitive control in multi-problem young adult men. There was a borderline significant association between post-error slowing and free-living physical activity, but due to the small sample size, it is not possible to draw any definite conclusions. Comparison with existing literature is further complicated as they focus on healthy young adults from the general population (Kamijo and Takeda, 2010, 2009; Padilla et al., 2014, 2013; Pérez et al., 2014; Ho et al., 2018; Salas-Gomez et al., 2020). In accordance with our results, a previous study could also not find a significant effect of physical activity level (low, moderate, high) measured with the IPAQ on a combined cued reaction time task and Flanker task in healthy young adult men and women. More specifically, this association remained non-significant even after reducing task complexity, reducing testing time, and increasing the cognitive load (Ho et al., 2018). Another study using the short version of the IPAQ did find a significant association between total amount of physical activity (measured with MET minutes) and the Stroop task, but not with the Trail-Making Task, and only in young adult woman, but not in men (Salas-Gomez et al., 2020).

The current non-significant findings may be due to the relatively high levels of physical activity in the multi-problem sample. Intervention studies predominantly focus on sedentary individuals, as there is converging evidence that sedentary individuals show impaired cognitive control compared to

active individuals (Colcombe and Kramer, 2003; Kamijo and Takeda, 2010, 2009) and thus would benefit the most from enhanced cognitive control through increased physical activity. However, these studies mostly rely on the WHO-guidelines to distinguish between sedentary and active individuals. It has been recently proposed that most health gains occur at 3000–4000 MET minutes per week rather than the recommended 900 MET, with significantly lower risk on multiple diseases including colon cancer and diabetes (Kyu et al., 2016). It may be that the current recommendations are too stringent to distinguish between active and non-active young adults and thus it may still be relevant for future studies to examine if increased physical activity could lead to increased cognitive control in multi-problem young adults. Lastly, it may be possible that other non-accounted for factors mediate or moderate the association between physical activity and cognitive control, such as structural brain abnormalities (Leshem, 2020) and maturation rate of the prefrontal cortex (PFC), an area important for cognitive control (Dahl, 2004; Veroude et al., 2013). Future studies should try to replicate these results, taking our current limitations into consideration.

The present study is not without limitations, as the small sample size (due to failure to complete all outcome measures and due to the COVID-19 pandemic) limits the interpretation of results, specifically in the testing of the association between physical activity and cognitive control. Also, regarding the Flanker task, it is possible that the time window and specifically the ISI was too short to elicit proper post-error slowing results. Although post-error slowing has been found in a similar sample with the same task duration (Zijlmans et al., 2019), a meta-analysis comparing post error slowing in ADHD patients vs. healthy participants showed that a larger ISI resulted in better post-error slowing in the controls than a smaller ISI (Balogh and Czobor, 2016). However, considering the exploratory aim of this study and the lack of research in an ecologically valid sample of multi-problem young adults, the current results could still provide us with valuable insights for future studies. For example, can increased physical activity in this (already active) sample still result in improved cognitive control, similar to results found in other (mostly sedentary) populations and age-groups (Hillman et al., 2008; Chaddock et al., 2010; Verburgh et al., 2014)?

In conclusion, our study is the first to examine self-reported free-living physical activity indexed by MET minutes per week in young adults facing multiple problems. Results indicate comparable levels of self-reported free-living physical activity as an age- and sex matched control sample, similar to other literature in students (Bergier et al., 2014) yet impaired cognitive control (measured with behavioral measures of error processing, response inhibition, and interference) relative to the controls. Despite existing limitations, the present study is the first to explore the association between physical activity and cognitive control in a multi-problem sample suffering cognitive control deficits, providing a starting point for future studies on this topic.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

This study involving human participants was reviewed and approved by the Scientific and Ethical Review Board of the VU University Amsterdam. The participants provided their written informed consent to participate in this study.

Author contributions

MES devised the project, collected the data, and analyzed the data. RM and ES supervised the data. MES wrote the manuscript in consultation with RM, PL, AP, and ES. All authors contributed to the article and approved the submitted version.

Funding

This research project was funded by Reclassering Nederland (the Dutch Probation Service). The financiers were not involved in the study design or manuscript drafting, nor in the processing, collecting, analyzing, and interpreting of data.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fnhum.2022.994123/full#supplementary-material>

References

- Ainsworth, B. E., Haskell, W. L., Whitt, M. C., Irwin, M. L., Swartz, A. M., Strath, S. J., et al. (2000). Compendium of physical activities: An update of activity codes and MET intensities. *Med. Sci. Sports Exerc.* 32, 498–516. doi: 10.1097/00005768-200009001-00009
- Bae, S., Ogawa, K., and Yamazaki, K. (2012). The relation between daily physical activity and response inhibition control in older adults: An event-related potential study using a Go/NoGo task. *Jpn. J. Phys. Fit. Sports Med.* 61, 169–176. doi: 10.7600/jspfsm.61.169
- Balogh, L., and Czobor, P. (2016). Post-error slowing in patients with ADHD: A meta-analysis. *J. Atten. Disord.* 20, 1004–1016. doi: 10.1177/1087054714528043
- Baumgartner, N. W., Walk, A. M., Edwards, C. G., Covello, A. R., Chojnacki, M. R., Reeser, G. E., et al. (2018). Relationship between physical activity, adiposity, and attentional inhibition. *J. Phys. Act. Health* 15, 191–196. doi: 10.1123/jpah.2017-0181
- Bellesi, G., Barker, E. D., Brown, L., and Valmaggia, L. (2019). Pediatric traumatic brain injury and antisocial behavior: Are they linked? A systematic review. *Brain Injury* 33, 1272–1292. doi: 10.1080/02699052.2019.1641621
- Bergier, B., Tsos, A., and Bergier, J. (2014). Factors determining physical activity of Ukrainian students. *Ann. Agric. Environ. Med.* 21, 613–616. doi: 10.5604/12321966.1120612
- Bergier, J., Bergier, B., and Tsos, A. (2016). Place of residence as a factor differentiating physical activity in the life style of Ukrainian students. *Ann. Agric. Environ. Med.* 23, 549–552. doi: 10.5604/12321966.1226844
- Bergier, J., Bergier, B., and Tsos, A. (2017). Variations in physical activity of male and female students from the Ukraine in health-promoting life style. *Ann. Agric. Environ. Med.* 24, 217–221. doi: 10.5604/12321966.1230674
- Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., et al. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *Br. J. Sports Med.* 54, 1451–1462. doi: 10.1136/bjsports-2020-102955
- Cameron, T. A., Lucas, S. J., and Machado, L. (2015). Near-infrared spectroscopy reveals link between chronic physical activity and anterior frontal oxygenated hemoglobin in healthy young women. *Psychophysiology* 52, 609–617. doi: 10.1111/psyp.12394
- Carnethon, M. R., Gidding, S. S., Nehgme, R., Sidney, S., Jacobs, D. R., and Liu, K. (2003). Cardiorespiratory Fitness in Young Adulthood and the Development of Cardiovascular Disease Risk Factors. *J. Am. Med. Assoc.* 290, 3092–3100. doi: 10.1001/jama.290.23.3092
- Chaddock, L., Erickson, K. I., Prakash, R. S., Kim, J. S., Voss, M. W., Vanpatter, M., et al. (2010). A neuroimaging investigation of the association between aerobic fitness, hippocampal volume, and memory performance in preadolescent children. *Brain Res.* 1358, 172–183. doi: 10.1016/j.brainres.2010.08.049
- Chester, V., Bunning, K., Tromans, S., Alexander, R., and Langdon, P. (2022). The Prevalence of Autism in the Criminal Justice System: A Systematic Review. *BJPsych Open* 8, S45–S46. doi: 10.1192/bjo.2022.179
- Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences*, 2nd Edn. Hillsdale, NJ: Lawrence Erlbaum Associates, Publishers.
- Colcombe, S., and Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: A meta-analytic study. *Psychol. Sci.* 14, 125–130. doi: 10.1111/1467-9280.t01-1-01430
- Corder, K., Winpenny, E., Love, R., Brown, H. E., White, M., and Sluijs, E. V. (2019). Change in physical activity from adolescence to early adulthood: A systematic review and meta-analysis of longitudinal cohort studies. *Br. J. Sports Med.* 53, 496–503. doi: 10.1136/bjsports-2016-097330
- Craig, F., Margari, F., Legrottaglie, A. R., Palumbi, R., de Giambattista, C., and Margari, L. (2016). A review of executive function deficits in autism spectrum disorder and attention-deficit/hyperactivity disorder. *Neuropsychiatr. Dis. Treat.* 12, 1191–1202. doi: 10.2147/NDT.S104620
- Dahl, R. E. (2004). Adolescent brain development: A period of vulnerabilities and opportunities - Keynote Address. *Ann. N Y Acad. Sci.* 1021, 1–22. doi: 10.1196/annals.1308.001
- Daskalopoulou, C., Stubbs, B., Kralj, C., Koukounari, A., Prince, M., and Prina, A. M. (2017). Physical activity and healthy ageing: A systematic review and meta-analysis of longitudinal cohort studies. *Ageing Res. Rev.* 38, 6–17. doi: 10.1016/j.arr.2017.06.003
- Diamond, A. (2013). Executive Functions. *Annu. Rev. Psychol.* 64:135. doi: 10.1146/annurev-psych-113011-143750
- Fischer, J., Butt, C., Dawes, H., Foster, C., Neale, J., Plugge, E., et al. (2012). Fitness levels and physical activity among class A drug users entering prison. *Br. J. Sports Med.* 46, 1142–1144. doi: 10.1136/bjsports-2011-090724
- Galioto Wiedemann, R., Calvo, D., Meister, J., and Spitznagel, M. B. (2014). Self-reported physical activity is associated with cognitive function in lean, but not obese individuals. *Clin. Obes.* 4, 309–315. doi: 10.1111/cob.12071
- Giles, G. E., Cantelon, J. A., Eddy, M. D., Bruny, T. T., Urry, H. L., Mahoney, C. R., et al. (2017). Habitual exercise is associated with cognitive control and cognitive reappraisal success. *Exp. Brain Res.* 235, 3785–3797. doi: 10.1007/s00221-017-5098-x
- Goenarjo, R., Bosquet, L., Berryman, N., Metier, V., Perrochon, A., Fraser, S. A., et al. (2020). Cerebral Oxygenation Reserve: The Relationship Between Physical Activity Level and the Cognitive Load During a Stroop Task in Healthy Young Males. *Int. J. Environ. Res. Public Health* 17:1406. doi: 10.3390/ijerph17041406
- Gomez-Pinilla, F., and Hillman, C. (2013). The influence of exercise on cognitive abilities. *Compr. Physiol.* 3, 403–428. doi: 10.1002/cphy.c110063
- Guiney, H., and Machado, L. (2013). Benefits of regular aerobic exercise for executive functioning in healthy populations. *Psychon. Bull. Rev.* 20, 73–86. doi: 10.3758/s13423-012-0345-4
- Guthold, R., Stevens, G. A., Riley, L. M., and Bull, F. C. (2020). Global trends in insufficient physical activity among adolescents: A pooled analysis of 298 population-based surveys with 1.6 million participants. *Lancet Child Adolesc. Health* 4, 23–35. doi: 10.1016/S2352-4642(19)30323-2
- Hagströmer, M., Oja, P., and Sjöström, M. (2006). The International Physical Activity Questionnaire (IPAQ): A study of concurrent and construct validity. *Public Health Nutr.* 9, 755–762. doi: 10.1079/PHN2005898
- Hiatt, K. D., Schmitt, W. A., and Newman, J. P. (2004). Stroop Tasks Reveal Abnormal Selective Attention among Psychopathic Offenders. *Neuropsychology* 18, 50–59. doi: 10.1037/0894-4105.18.1.50
- Hillman, C. H., Castelli, D. M., and Buck, S. M. (2005). Aerobic fitness and neurocognitive function in healthy preadolescent children. *Med. Sci. Sports Exerc.* 37, 1967–1974. doi: 10.1249/01.mss.0000176680.79702.ce
- Hillman, C. H., Erickson, K. I., and Kramer, A. F. (2008). Be smart, exercise your heart: Exercise effects on brain and cognition. *Nat. Rev. Neurosci.* 9, 58–65. doi: 10.1038/nrn2298
- Ho, S., Kyle Gooderham, G., and Handy, T. C. (2018). Self-reported free-living physical activity and executive control in young adults. *PLoS One* 13:e0209616. doi: 10.1371/journal.pone.0209616
- Hogan, M., Kiefer, M., Kubesch, S., Collins, P., Kilmartin, L., and Brosnan, M. (2013). The interactive effects of physical fitness and acute aerobic exercise on electrophysiological coherence and cognitive performance in adolescents. *Exp. Brain Res.* 229, 85–96. doi: 10.1007/s00221-013-3595-0
- IBM (2011). *IBM SPSS Statistics for Windows, Version 20.0*. Albany, NY: IBM.
- Junger, M., Stroebe, W., and Van der Laan, A. M. (2001). Delinquency, health behaviour and health. *Br. J. Health Psychol.* 6, 103–120. doi: 10.1348/135910701169098
- Kamijo, K., and Takeda, Y. (2009). General physical activity levels influence positive and negative priming effects in young adults. *Clin. Neurophysiol.* 120, 511–519. doi: 10.1016/j.clinph.2008.11.022
- Kamijo, K., and Takeda, Y. (2010). Regular physical activity improves executive function during task switching in young adults. *Int. J. Psychophysiol.* 75, 304–311. doi: 10.1016/j.ijpsycho.2010.01.002
- Kamijo, K., Yoichi, H., Sakai, T., Yahiro, T., Tanaka, K., and Nishihira, Y. (2009). Acute effects of aerobic exercise on cognitive function in older adults. *J. Gerontol. B Psychol. Sci. Soc. Sci.* 64, 356–363. doi: 10.1093/geronb/gbp030
- Kantamäa, M. T., Tammelin, T. H., Ebeling, H. E., and Taanila, A. M. (2008). Emotional and behavioral problems in relation to physical activity in youth. *Med. Sci. Sports Exerc.* 40, 1749–1756. doi: 10.1249/MSS.0b013e31817b8e82
- Krieger, H., Young, C. M., Anthenien, A. M., and Neighbors, C. (2018). The Epidemiology of Binge Drinking Among College-Age Individuals in the United States. *Alcohol. Res.* 39:23.
- Kyu, H. H., Bachman, V. F., Alexander, L. T., Mumford, J. E., Afshin, A., Estep, K., et al. (2016). Physical activity and risk of breast cancer, colon cancer, diabetes, ischemic heart disease, and ischemic stroke events: Systematic review and dose-response meta-analysis for the Global Burden of Disease Study 2013. *BMJ* 354:i3857. doi: 10.1136/bmj.i3857
- Lesher, R. (2020). There are more than two sides to antisocial behavior: The inextricable link between hemispheric specialization and environment. *Symmetry* 12, 1–16. doi: 10.3390/sym12101671
- Lubans, D. R., Plotnikoff, R. C., and Lubans, N. J. (2012). Review: A systematic review of the impact of physical activity programmes on social and emotional well-being in at-risk youth. *Child Adolesc. Ment. Health* 17, 2–13. doi: 10.1111/j.1475-3588.2011.00623.x

- Luijckx, M. J. A., Bevaart, F., Zijlmans, J., van Duin, L., Marhe, R., Doreleijers, T. A., et al. (2017). A multimodal day treatment program for multi-problem young adults: Study protocol for a randomized controlled trial. *Trials* 18:225. doi: 10.1186/s13063-017-1950-3
- Luijckx, M., Veltman, D. J., Hester, R., Smits, M., Nijs, I. M., Pepplinkhuizen, L., et al. (2013). The role of dopamine in inhibitory control in smokers and non-smokers: A pharmacological fMRI study. *Eur. Neuropsychopharmacol.* 23, 1247–1256. doi: 10.1016/j.euroneuro.2012.12.016
- Marhe, R., van de Wetering, B. J., and Franken, I. H. (2013). Error-related brain activity predicts cocaine use after treatment at 3-month follow-up. *Biol. Psychiatry* 73, 782–788. doi: 10.1016/j.biopsych.2012.12.016
- Marques, A., Sarmiento, H., Martins, J., and Saboga Nunes, L. (2015). Prevalence of physical activity in European adults - Compliance with the World Health Organization's physical activity guidelines. *Prev. Med.* 81, 333–338. doi: 10.1016/j.ypmed.2015.09.018
- Morgan, A. B., and Lilienfeld, S. O. (2000). A meta-analytic review of the relation between antisocial behavior and neuropsychological measures of executive function. *Clin. Psychol. Rev.* 20, 113–136. doi: 10.1016/S0272-7358(98)00096-8
- Nijman, H., Kaal, H., van Scheppingen, L., and Moonen, X. (2018). Development and Testing of a Screener for Intelligence and Learning Disabilities (SCIL). *J. Appl. Res. Intellect. Disabil.* 31, e59–e67. doi: 10.1111/jar.12310
- Ogilvie, J. M., Stewart, A. L., Chan, R. C. K., and Shum, D. H. K. (2011). Neuropsychological measures of executive function and antisocial behavior: A meta-analysis. *Criminology* 49, 1063–1107. doi: 10.1111/j.1745-9125.2011.00252.x
- Padilla, C., Pérez, L., and Andrés, P. (2014). Chronic exercise keeps working memory and inhibitory capacities fit. *Front. Behav. Neurosci.* 8:49. doi: 10.3389/fnbeh.2014.00049
- Padilla, C., Perez, L., Andres, P., and Parmentier, F. B. R. (2013). Exercise improves cognitive control: Evidence from the stop signal task. *Appl. Cogn. Psychol.* 27, 505–511. doi: 10.1002/acp.2929
- Paluska, S. A., and Schwenk, T. L. (2000). Physical activity and mental health: Current concepts. *Sports Med.* 29, 167–180. doi: 10.2165/00007256-200029030-00003
- Pérez, L., Padilla, C., Parmentier, F. B. R., and Andrés, P. (2014). The effects of chronic exercise on attentional networks. *PLoS One* 9:e101478. doi: 10.1371/journal.pone.0101478
- Rebar, A. L., Stanton, R., Gerd, D., Short, C., Duncan, M. J., and Vandelanotte, C. (2015). A meta-meta-analysis of the effect of physical activity on depression and anxiety in non-clinical adult populations. *Health Psychol. Rev.* 9, 366–378. doi: 10.1080/17437199.2015.1022901
- Riebe, D., Ehrman, J. K., Liguori, G., and Magal, M. (2018). *ACSM's Guidelines for Exercise Testing and Prescription*, (10 Edn). Philadelphia: Wolters Kluwer.
- Salas-Gomez, D., Fernandez-Gorgojo, M., Pozueta, A., Diaz-Ceballos, I., Lamarain, M., Perez, C., et al. (2020). Physical Activity Is Associated With Better Executive Function in University Students. *Front. Hum. Neurosci.* 14:11. doi: 10.3389/fnhum.2020.00011
- Schretlen, D. J., and Shapiro, A. M. (2003). A quantitative review of the effects of traumatic brain injury on cognitive functioning. *Int. Rev. Psychiatry.* 15, 341–349.
- Singh, G. K., Kogan, M. D., Siahpush, M., and Van Dyck, P. C. (2008). Independent and joint effects of socioeconomic, behavioral, and neighborhood characteristics on physical inactivity and activity levels among US children and adolescents. *J. Community Health* 33, 206–216. doi: 10.1007/s10900-008-9094-8
- Smith, P. J., Blumenthal, J. A., Hoffman, B. M., Cooper, H., Strauman, T. A., Welsh-Bohmer, K., et al. (2010). Aerobic exercise and neurocognitive performance: A meta-analytic review of randomized controlled trials. *Psychosom. Med.* 72, 239–252. doi: 10.1097/PSY.0b013e3181d14633
- Song, M., Carroll, D. D., and Fulton, J. E. (2013). Meeting the 2008 Physical Activity Guidelines for Americans among U.S. youth. *Am. J. Prev. Med.* 44, 216–222. doi: 10.1016/j.amepre.2012.11.016
- Spinney, J., and Millward, H. (2010). Time and Money: A New Look at Poverty and the Barriers to Physical Activity in Canada. *Soc. Indic. Res.* 99, 341–356. doi: 10.1007/s11205-010-9585-8
- Stalsberg, R., and Pedersen, A. V. (2010). Effects of socioeconomic status on the physical activity in adolescents: A systematic review of the evidence. *Scand. J. Med. Sci. Sports* 20, 368–383. doi: 10.1111/j.1600-0838.2009.01047.x
- Stoet, G. (2010). PsyToolkit: A software package for programming psychological experiments using Linux. *Behav. Res. Methods* 42, 1096–1104. doi: 10.3758/BRM.42.4.1096
- Stoet, G. (2017). PsyToolkit: A Novel Web-Based Method for Running Online Questionnaires and Reaction-Time Experiments. *Teach. Psychol.* 44, 24–31. doi: 10.1177/0098628316677643
- Storebø, O. J., and Simonsen, E. (2016). The association between ADHD and antisocial personality disorder (ASPD) a review. *J. Atten. Disord.* 20, 815–824. doi: 10.1177/1087054713512150
- Swann, A. C., Lijffijt, M., Lane, S. D., Steinberg, J. L., and Moeller, F. G. (2009). Trait impulsivity and response inhibition in antisocial personality disorder. *J. Psychiatr. Res.* 43, 1057–1063.
- Thorp, A. A., Healy, G. N., Winkler, E., Clark, B. K., Gardiner, P. A., Owen, N., et al. (2012). Prolonged sedentary time and physical activity in workplace and non-work contexts: A cross-sectional study of office, customer service and call centre employees. *Int. J. Behav. Nutr. Phys. Act.* 9:128. doi: 10.1186/1479-5868-9-128
- Turner, D., Laier, C., Brand, M., Bockshammer, T., Welsch, R., and Rettenberger, M. (2018). Response inhibition and impulsive decision-making in sexual offenders against children. *J. Abnorm. Psychol.* 127, 471–481. doi: 10.1037/abn0000359
- Valle, C. G., Tate, D. F., Mayer, D. K., Allicock, M., Cai, J., and Campbell, M. K. (2015). Physical activity in young adults: A signal detection analysis of Health Information National Trends Survey (HINTS) 2007 data. *J. Health Commun.* 20, 134–146. doi: 10.1080/10810730.2014.917745
- van der Niet, A. G., Smith, J., Scherder, E. J. A., Oosterlaan, J., Hartman, E., and Visscher, C. (2015). Associations between daily physical activity and executive functioning in primary school-aged children. *J. Sci. Med. Sport* 18, 673–677. doi: 10.1016/j.jsams.2014.09.006
- van der Sluys, M. E., Zijlmans, J., Popma, A., van der Laan, P. H., Scherder, E. J. A., and Marhe, R. (2020). Neurocognitive predictors of treatment completion and daytime activities at follow-up in multiproblem young adults. *Cogn. Affect. Behav. Neurosci.* 20, 1103–1121. doi: 10.3758/s13415-020-00822-4
- van Duin, L., Bevaart, F., Paalman, C. H., Luijckx, M. J. A., Zijlmans, J., Marhe, R., et al. (2017). Child Protection Service interference in childhood and the relation with mental health problems and delinquency in young adulthood: A latent class analysis study. *Child Adolesc. Psychiatry Ment. Health* 11:66. doi: 10.1186/s13034-017-0205-0
- van Duin, L., Bevaart, F., Zijlmans, J., Luijckx, M. J. A., Doreleijers, T. A., Wierdsma, A. I., et al. (2018). The role of adverse childhood experiences and mental health care use in psychological dysfunction of male multi-problem young adults. *Eur. Child Adolesc. Psychiatry* 28, 1065–1078. doi: 10.1007/s00787-018-1263-4
- Verburgh, L., Königs, M., Scherder, E. J. A., and Oosterlaan, J. (2014). Physical exercise and executive functions in preadolescent children, adolescents and young adults: A meta-analysis. *Br. J. Sports Med.* 48, 973–979. doi: 10.1136/bjsports-2012-091441
- Veroude, K., Jolles, J., Croiset, G., and Krabbendam, L. (2013). Changes in neural mechanisms of cognitive control during the transition from late adolescence to young adulthood. *Dev. Cogn. Neurosci.* 5, 63–70. doi: 10.1016/j.dcn.2012.12.002
- Weidacker, K., Snowden, R. J., Boy, F., and Johnston, S. J. (2017). Response inhibition in the parametric Go/No-Go task in psychopathic offenders. *Psychiatry Res.* 250, 256–263. doi: 10.1016/j.psychres.2017.01.083
- World Health Organization [WHO] (2020). *Physical Activity*. Available online at: <https://www.who.int/dietphysicalactivity/pa/en/> (accessed on 18 May, 2020)
- Zeier, J. D., Baskin-Sommers, A. R., Hiatt Racer, K. D., and Newman, J. P. (2012). Cognitive control deficits associated with antisocial personality disorder and psychopathy. *Personal. Disord.* 3, 283–293. doi: 10.1037/a0023137
- Zhu, Y., Sun, F., Chow, G. C., Tao, S., Cooper, S. B., Zhang, B., et al. (2022). Associations of Device-Measured Physical Activity, Sedentary Behavior, and Executive Function in Preadolescents: A Latent Profile Approach. *Pediatr. Exerc. Sci.* 1, 1–7. doi: 10.1123/pes.2022-0016
- Zijlmans, J., Marhe, R., Bevaart, F., Luijckx, M. J. A., van Duin, L., Tiemeier, H., et al. (2018). Neural correlates of moral evaluation and psychopathic traits in male multi-problem young adults. *Front. Psychiatry* 9:248. doi: 10.3389/fpsy.2018.00248
- Zijlmans, J., Bevaart, F., van Duin, L., Luijckx, M. J. A., Popma, A., and Marhe, R. (2019). Error-related brain activity in relation to psychopathic traits in multi-problem young adults: An ERP study. *Biol. Psychol.* 144, 46–53. doi: 10.1016/j.biopsycho.2019.03.014
- Zijlmans, J., Marhe, R., Bevaart, F., Duin, L., Luijckx, M. A., Franken, I., et al. (2020a). The predictive value of neurobiological measures for recidivism in delinquent male youngsters. *J. Am. Acad. Child Adolesc. Psychiatry* 59:1546. doi: 10.1016/j.jaac.2020.08.049
- Zijlmans, J., van Duin, L., Jorink, M., Marhe, R., Luijckx, M. A., Crone, M., et al. (2020b). Disentangling multiproblem behavior in male young adults: A cluster analysis. *Dev. Psychopathol.* 33, 149–159. doi: 10.1017/S0954579419001652