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2023

DOI (link to publisher)
10.5463/thesis.462

document version
Publisher's PDF, also known as Version of record

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The effect of physical activity on cognitive control and antisocial behavior

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Cover design by Simone Golob

Printed by Proefschriftmaken

This research was funded by Reclassering Nederland (Dutch Probation Service) and Arnold Oosterbaan Hersenstichting. The financer was not involved in the design of the study, the drafting of the manuscript, nor was it involved in the process of data collection, analysis, and interpretation.

VRIJE UNIVERSITEIT

Move to Improve

The effect of physical activity on cognitive control and antisocial behavior

ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad Doctor of Philosophy aan

de Vrije Universiteit Amsterdam,

op gezag van de rector magnificus

prof.dr. J.J.G. Geurts,

in het openbaar te verdedigen

ten overstaan van de promotiecommissie

van de Faculteit der Gedrags- en Bewegingswetenschappen

op woensdag 13 december 2023 om 9.45 uur

in een bijeenkomst van de universiteit,

De Boelelaan 1105

door

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geboren te Nijmegen

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CHAPTER 1

General introduction

Multi-problem young adults and antisocial behavior

Emerging adulthood or the transition from late adolescence into young adulthood (aged 18-26), is a turbulent period characterized by identity exploration (Schwartz et al., 2013), increased independence (Nelson & Barry, 2005), and several developmental changes (Arnett, 2000; Vecchione et al., 2012; Wood et al., 2017). This phase is associated with a growing emphasis on self-sufficiency as parental support and institutional structure decline, and social expectations change. Some young adults may thrive as a result of the increased autonomy (Schulenberg & Zarrett, 2007), but for others, the related increase in responsibilities is accompanied by a peak prevalence in mental disorders (Tanner et al., 2007), substance (ab)use (Stone et al., 2012), and criminal offenses (Loeber et al., 2013). Emerging adulthood can be especially challenging for vulnerable populations who require extra support to achieve a normal transition (Osgood et al., 2010). They can develop into multi-problem young adults (aged 18-27) who are presented with complications in several key life domains, i.e., mental health, social network, addiction, and justice (Luijks et al., 2017). Their transition is marked by an accumulation of problems, including a history of childhood adversity, behavioral and psychiatric disorders, unemployment, financial problems, low education, substance (ab)use, and a history of delinquency (van Duin et al., 2017; Zijlmans et al., 2020). They often lack sufficient resilience and resources (Osgood et al., 2010) and are therefore unable to navigate into healthy adulthood (Arnett, 2007).

One particularly important topic in emerging young adults is the occurrence and persistence of antisocial behavior (Donker et al., 2003; Jennings & Reingle, 2012; Loeber & Farrington, 2012; Thornberry et al., 2012). Such behavior negatively affects both perpetrator and victim, generating substantial societal costs (estimated at more than $1.7 trillion annually in the United States alone) (Anderson, 2012). Antisocial behavior can be conceptualized as a collection of heterogeneous behaviors violating legal or moral rules (Moffitt, 2017). This includes rule-breaking behavior such as criminal offenses, externalizing behavior correlating with antisocial personality traits, and aggression (Burt, 2009). A further functional distinction has been proposed, distinguishing between proactive aggression (premeditated, instrumental, and offensive) and reactive aggression (defensive, in reaction to an anticipated anger-associated threat) (Dodge et al., 1990). Different types of maladaptive behavior may have different underlying mechanisms, which becomes evident in the case of aggression. While these two types are correlated, they exhibit distinct social-cognitive processes (i.e., divergent correlates with social information processing steps (Castro, 2004; Hubbard et al., 2010), unique associated personality traits and different related cognitive distortions (i.e., biased thinking patterns) (Koolen et al., 2012). This may also be true for other problematic behaviors (e.g., offenses, antisocial personality problems) (Tremblay, 2010), stressing the need to consider antisocial behavior as a heterotypical construct encompassing more than registered acts of delinquency or diagnosed clinical disorders (e.g. conduct disorder or antisocial personality disorder) (Ogilvie et al., 2011; Popovici et al., 2014; Pulkkinen, 2001).

To develop early prevention and to reduce monetary and other costs of antisocial behavior, more information is needed on the origins of such unwanted behavior. Not all young adults display antisocial behavior and even within those that do, there are large individual differences in the development and severity (Blonigen et al., 2010; Diamantopoulou et al., 2010; Donker et al., 2003; Eggleston & Laub, 2002; Moffitt, 2017). Although antisocial or disruptive behaviors generally peak during late adolescence and decline during emerging adulthood (Hyde et al., 2018), results indicate individual trajectories in the antisocial development from youth to adulthood. These include adolescence-limited (desistance during young adulthood), late-onset (problems manifest during young adulthood), and life-course-persistent (antisocial tendencies continue from adolescence to adulthood) (Blonigen et al., 2010; Diamantopoulou et al., 2010; Donker et al., 2003; Eggleston & Laub, 2002; Moffitt, 2017). Besides these developmental subtypes, there are developmental pathways describing the progression of antisocial behavior. For example, Loeber and colleagues argued that serious problem behaviors are preceded by less serious problems in three domains: authority conflict (defiance, running away), overt (aggression, violence), and covert (stealing, lying) (Loeber et al., 1993). Consequently, it is important to examine the source of these different subtypes and pathways, to recognize young adults at risk for more persistent and severe antisocial behavior. Increasing efforts have been made to search for such antisocial markers from a multidimensional approach, such as the biopsychosocial perspective. This framework posits that antisocial behavior is the result of the interplay between psychosocial and neurobiological factors (Beauchaine et al., 2008; Popma & Raine, 2006), including brain abnormalities in the prefrontal cortex (Yang & Raine, 2009), impaired cognitive control (Pharo et al., 2011), cognitive distortions (Wallinius et al., 2011), high levels of impulsivity (Maneiro et al., 2022; Marzilli et al., 2021), and frequent substance use (Hill et al., 2018). However, these studies mostly failed to address the heterogeneous nature of antisocial behavior or did not consider ecologically valid samples such as multi-problem young adults.

Existng research in antisocial behavior predominantly concentrates on adolescents as they show an increase in criminal behavior observed as the densest area in the age-crime curve, e.g., (Hubbard et al., 2010; Loeber et al., 1993; Maneiro et al., 2017; Moffitt, 2017; Pulkkinen, 2001; Sterzer, 2009; van der Laan et al., 2009). In contrast, there are far fewer studies focusing on emerging young adults (Basto-Pereira et al., 2020; Blonigen et al., 2010; Hill et al., 2018; Kessler, 2020), despite the identification of late-onset offenders without prior problem behavior (Donker et al., 2003; Eggleston & Laub, 2002). This trend can also be seen in traditional justice systems, as they are often designed for youth (aged < 18) or adults (aged > 18) and are therefore not equipped to address the needs of youths in transition (Hammer & Hyggen, 2010; Osgood et al., 2010), (but see, for example (Schmidt et al., 2021) for recent adaptations of the Dutch law). Young adults who do not receive the appropriate care have a high risk of becoming lost in transition (Barrow Cadbury Trust, 2005). This is even more the case for multi-problem young adults, who are suffering from a range of social, psychological, and financial problems (Ellem et al., 2020; Zijlmans et al., 2020). To accommodate these and other emerging adults, more age-appropriate and effective interventions are necessary (Ellem et al., 2020), as current interventions targeting antisocial behavior have limited effectiveness (Fazel & Wolf, 2015; van der Put et al., 2016). One proposed way to increase treatment efficacy is by targeting the underlying (neurocognitive) correlates, rather than focusing on changing the behavioral outcome (Ogilvie et al., 2011). To do so, more insight is needed into which neurocognitive factors predict and enable antisocial behavior in young adults (Kessler, 2020). In this regard, cognitive control may be a particularly important source, as it might mitigate or facilitate socially unwanted behavior through the (ineffective) exertion of self-control and behavior regulation (Loeber et al., 2007; Siever, 2008).

Cognitive control

There is apt research associating antisocial behavior with impaired cognitive control (Morgan & Lilienfeld, 2000; Ogilvie et al., 2011; Pharo et al., 2011). Cognitive control or executive functioning refers to a collection of cognitive abilities (e.g., inhibition, attention, set-shifting, process monitoring) crucial for planned and goal-oriented behavior (Diamond, 2013; Gazzaley & D'Esposito, 2007; Sira & Mateer, 2014). Deficits in these higher-order cognitive functions can result in the impaired capacity to self-regulate and adjust behavior, which may facilitate maladaptive and rule-breaking behavior. Neurocognitive impairments correlated to such behavior include an inability to suppress inappropriate behavior (i.e., response inhibition), an inability to detect and react to errors (i.e., error processing), and an inability to inhibit a dominant response in favor of a less dominant response (i.e., cognitive interference) (Hiatt et al., 2004; Swann et al., 2009; Turner et al., 2018; Weidacker et al., 2017; Zeier et al., 2012). These deficits can be observed during neuropsychological testing as aberrant behavioral responses (e.g., low accuracy, shorter reaction times) (Chamberlain et al., 2016; Ogilvie et al., 2011) or aberrant neurobiological responses (e.g., abnormal functional brain activity or electrophysiological measurements) (Aharoni et al., 2013; Guan et al., 2015; Sterzer, 2009; Yang & Raine, 2009; Zijlmans et al., 2019, 2021).

Evidence for impaired neurocognitive functioning at the behavioral level can be found in criminological research. For example, compared to non-offending populations, adult offenders show impaired response inhibition as measured with slower reaction times and more errors (Turner et al., 2018; Weidacker et al., 2017), poor error processing indexed as low accuracy (Zeier et al., 2012), and increased cognitive interference observed as a larger difference in reaction time between congruent and incongruent trials (Hiatt et al., 2004). In addition to behavioral measures, there are neurobiological markers of cognitive control. These include event-related potentials (ERPs) and brain activity in the anterior cingulate cortex (ACC: brain area most involved in cognitive control functioning (Nieuwenhuis et al., 2003)) during task performance. Two important ERPs are error-related negativity (ERN) and error-related positivity (Pe), which reflect psychophysiological indices of error processing measured during electroencephalography (Nieuwenhuis et al., 2001). Based on source-localization studies, it has been argued that these measures are generated, among other brain regions, in the ACC (Edwards et al., 2012; Orr & Hester, 2012). Relatedly, activity in the ACC has been postulated to reflect response inhibition on a neural level (Aharoni et al., 2013; Braver et al., 2001). Neuroimaging studies have shown altered activity in these cognitive control correlates in individuals displaying externalizing behavior, such as reduced Pe amplitude in adult offenders during error processing (Brazil et al., 2009; Steele et al., 2016) and reduced ACC activity in adult drug abusers during response inhibition (Hester et al., 2009) compared to healthy controls. In sum, data from several studies have demonstrated a link between antisocial behavior and impaired neurocognitive functioning, manifested as aberrant behavioral and neurobiological responses. Still, most of these studies included adult clinical populations such as offenders (Brazil et al., 2009; Hiatt et al., 2004; Turner et al., 2018; Weidacker et al., 2017) and substance abusers (Kirisci et al., 2004; Luijten et al., 2014; Marhe et al., 2013; Steele et al., 2014).

Whilst some research has been carried out on young adults from the general population (e.g., (Dotterer et al., 2021; Patrick et al., 2008)), so far, relatively little attention has been paid to clinical or at-risk young adults, or on the occurrence of multiple problems simultaneously (but see (Wallinius et al., 2019; Zijlmans et al., 2019, 2021)). Results from the limited existing research suggest impaired cognitive control in young adults suffering from several problems (Zijlmans et al., 2019, 2021), indicating they might benefit from interventions specifically targeting this higher-order cognition. Enhanced cognitive control can improve the ability to anticipate negative outcomes, exert effortful control, and self-regulate behavior (Gardner et al., 2008; Loeber et al., 2007; Nigg et al., 2007), which in turn may result in decreased antisocial behavior. Some modest efforts have been made to increase cognitive control in non-antisocial populations, for example with cognitive training (especially working memory training) or meditation, yet these cognitive interventions are time-consuming, expensive, or have limited non-generalized effects (e.g., (Melby-Lervåg & Hulme, 2013; Sedlmeier et al., 2012)). Another promising intervention targeting neurocognitive functioning encompasses increased physical activity (Verburgh et al., 2014), as it is easy to implement and inexpensive.

Physical activity

Physical activity can be defined as any skeletal muscle-induced movement requiring energy expenditure (Caspersen et al., 1985) and it is associated with various physical and mental health benefits, such as a reduced risk of cardiovascular disease and decreased depression-related symptoms (Daskalopoulou et al., 2017; Lubans et al., 2012). Regardless of these beneficial effects, on average, physical activity seems to decline from adolescence to young adulthood (Corder et al., 2019). As a result, most young adults do not meet the weekly 150 min of moderate-to-vigorous or 75 min of vigorous physical activity as recommended by the World Health Organization (WHO) (Marques et al., 2015; Song et al., 2013). Being inactive might put them at an increased risk for maladaptive behaviors such as smoking and substance use compared to their more active peers (Dunn & Wang, 2003; Henchoz et al., 2014).

Policymakers and (youth) offender institutions have been increasingly recognizing the value of physical activity programs in the prevention and rehabilitation of antisocial behavior, especially in children and adolescents (Ekholm et al., 2013; Meek, 2018; Taylor et al., 2015). Indeed, there is a large number of studies establishing the efficacy of physical activity interventions in the reduction of various externalizing behaviors, including anger, aggression, violence, and substance-related problems in youth (aged < 18) from the general population (for meta-analytic reviews, see (Gubbels et al., 2016; Simonton et al., 2018; Spruit et al., 2016)). This is further supported in adult offenders (Meek, 2018) and other adult populations displaying antisocial behavior such as adult substance abusers (Wang et al., 2014). In contrast, mixed results are found in the (scarce) existing literature on young adults (Hartmann & Depro, 2006; Sampson & Vilella, 2014; Welland et al., 2020). As such, there is still uncertainty about the efficacy of physical activity interventions during this transitional phase. Moreover, a systematic understanding of how it might contribute to positive behavioral changes is still lacking. Research to date observed several important factors, ranging from improved social learning (Bandura, 1973; Gubbels et al., 2016), self-worth (Bowker, 2006; Liu et al., 2015), and feelings of social inclusion (Perks, 2007), to enhanced neurocognitive functioning (Jackson & Beaver, 2018). In this regard, the role of cognitive control seems particularly compelling, given the cognitive control deficits related to antisocial behavior and the promising results in youth and adults from the general population.

A growing body of literature suggests that increased regular (i.e., chronic) physical activity can result in improved cognitive control, with the most robust findings for sedentary but healthy children (Álvarez-Bueno et al., 2017), adolescents (S. Liu et al., 2020), and older adults (Chen et al., 2020). However, information on young adults is limited and less conclusive (for similar conclusions, see: (Hillman et al., 2008; Stillman et al., 2020; Verburgh et al., 2014)). Moreover, somewhat surprisingly, these existing studies mostly focus on young adults from the general population and not on those displaying antisocial behavior (Hillman et al., 2008; Stillman et al., 2020; Verburgh et al., 2014)), despite the possible advantages for this population (Jackson & Beaver, 2018; Zijlmans et al., 2019, 2021). Results from related studies in emerging adults with known neurocognitive impairments (i.e., suffering from Attention-Deficit-Hyperactivity Disorder (ADHD)) suggest physical activity interventions may indeed be effective in individuals with impaired cognitive control (Barkley et al., 2018). A neurobiological explanation could be that various activity-induced processes may contribute to better neurocognitive functioning through higher neural efficiency (Erickson et al., 2015), including increased cerebral oxygenation (Goenarjo et al., 2020) and increased cortical thickness in the frontal lobe (Stern et al., 2019). Still, to date, these processes are not fully understood in young adults (Stillman et al., 2020) in whom frontal systems are not yet completely matured (Steinberg, 2008). To summarize, whilst physical activity interventions have been increasingly used to enhance neurocognitive functions in sedentary but otherwise healthy youth and the elderly (Álvarez-Bueno et al., 2017; Chen et al., 2020; Liu et al., 2020) and young adults suffering from neurocognitive impairments such as ADHD (Barkley et al., 2018), it remains unclear if this is also the case in young adults with co-occurring and complex problems, including antisocial behavior.

The current dissertation

To guide the development of preventive programs and implement physical activity as a widespread intervention targeting antisocial behavior, more information is needed on the underlying mechanisms including cognitive control. In addition, it is important to address the heterogeneous nature of antisocial behavior by examining different types of disruptive behavior (Ogilvie et al., 2011; Popovici et al., 2014; Pulkkinen, 2001). Physical activity has been previously proposed as a viable and effective intervention in the reduction of antisocial behavior in youth (aged < 18) from the general population (Gubbels et al., 2016; Simonton et al., 2018; Spruit et al., 2016) and clinical adult populations (Meek, 2018; Wang et al., 2014). This reduction may be the result of an increase in executive functions (Álvarez-Bueno et al., 2017; Chen et al., 2020; Jackson & Beaver, 2018; Liu et al., 2020), although the literature on this effect in young adults is scarce and mixed (Hillman et al., 2008; Stillman et al., 2020; Verburgh et al., 2014). Enhanced cognitive control is especially relevant in populations displaying antisocial or externalizing behavior with known cognitive control deficits, such as offenders (Brazil et al., 2009; Hiatt et al., 2004; Turner et al., 2018; Weidacker et al., 2017) and substance abusers (Kirisci et al., 2004; Luijten et al., 2014; Marhe et al., 2013; Steele et al., 2014). Less established is this association in populations displaying co-occurring negative behaviors, although indications for similar neurocognitive deficits are found in multi-problem young adults (Zijlmans et al., 2019, 2021). Yet to date, to the author's knowledge, there are no known physical activity interventions targeting neurocognitive functions in (young) adults with overlapping and complex problems. To overcome this gap and previous limitations, the current dissertation examines neurobiological and behavioral indices of cognitive control associated with antisocial behaviors (e.g., criminal offenses, aggression, frequent substance use) in young adults suffering from multiple (behavioral, psychological, and other) problems, including a history of delinquency and frequent substance use. Furthermore, we aim to discern the possible role of physical activity to improve these processes, to ultimately decrease antisocial behavior.

To do so, we analyzed data from a sample of 63 young male adults (aged 18-27) experiencing severe complications in several important life domains including lack of finances, no daily activities, no social support, behavioral problems, low mental health, alcohol or substance addiction, and high involvement with justice (Zijlmans et al., 2020). Due to the existing elevated risk of comorbidity during emerging adulthood (de la Torre-Luque et al., 2022) and the bidirectional reinforcing association between some of these problems (e.g., (Anakwenze & Zuberi, 2013; Conway, 2005; Kjelsberg, 2008)), it is not uncommon for vulnerable young adults to develop into multi-problem young adults. This risk becomes even more apparent in large urban cities (Anakwenze & Zuberi, 2013) where compared to rural areas, overall there is less social cohesion ((Avery et al., 2021), a higher prevalence of mental disorders (Peen et al., 2010), higher crime rates (Weisburd, 2015), and subsequent a higher risk on and fear of victimization (Thomspon & Tapp, 2022). To support troubled young adults with their transition into emerging adulthood, specialized and multi-faceted treatment is needed. One such intervention is situated in Rotterdam (large urban city in the Netherlands), where a multimodal day treatment program called De Nieuwe Kans (DNK; translated as “New Opportunities”) was specifically designed to aid male multi-problem young adults (aged 18-27) (Luijks et al., 2017). This program aims to guide young adults to education, employment, or, if deemed necessary, to referred specialized care. To accomplish these goals, DNK applies a multidimensional approach combining education, practical lessons (e.g., cooking, sports), cognitive behavioral techniques, and rehabilitation components such as drug treatment. The ultimate goal is to increase self-sufficiency and subsequently decrease antisocial behavior in these troubled young adults. All participants were recruited at the start of their DNK treatment program. Two studies (Chapters 2 and 3) were performed using previously collected functional magnetic resonance and electroencephalographic data in a cohort of 696 multi-problem young adults, recruited at the same site (Zijlmans et al., 2019, 2021).

Taken together, this thesis comprises six studies addressing the heterotypical nature of antisocial behavior in an ecologically valid sample (Chapters 2 through 7), using neurobiological indices of cognitive control (Chapters 2 and 3), quantitative measures of the effectiveness of physical activity interventions related to antisocial behavior and cognitive control (Chapters 4 to 6), and a qualitative investigation of the role of physical activity (Chapter 7).

Chapter 2 describes the association with neurobiological measures of cognitive control in multi-problem young adults and treatment outcome (completion and the acquisition of daytime activities a year after the start of treatment), over and above psychological, social, and criminal characteristics.

Chapter 3 explores whether specific self-serving cognitive distortions (pro-criminal biases) are differently related to antisocial behaviors (number of criminal offenses, antisocial personality traits, proactive and reactive aggression) in multi-problem young adults. As a second aim, the moderating role of neurobiological measures of cognitive control is examined, providing more insight into possible treatment options concerning antisocial behavior.

Chapter 4 reviews and quantifies the effect of physical activity interventions in the reduction of antisocial behavior in children and adults at risk of (re-)offending or those from the general population displaying antisocial behavior.

Chapter 5 investigates the possible association between physical activity levels and cognitive control at the start of a multimodal day treatment program in multi-problem young adults. It also confirms impaired cognitive control in the multi-problem sample compared to age- and sex-matched controls from the general population.

Chapter 6 concerns the results of six weeks of moderately intensive physical activity versus six weeks of light physical activity embedded in a multimodal day treatment program, on cognitive control and trait impulsivity in multi-problem young adults.

Chapter 7 is a qualitative study on the role of physical activity in the lives of multi-problem young adults and explores their views on other ways in which physical activity can be used to support them.

CHAPTER 2

Neurocognitive predictors of treatment completion and daytime activities at follow-up in multi-problem young adults

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Cognitive, Affective & Behavioral Neuroscience, 2020, *20*(5), 1103–1121

Abstract

Previous research has shown an association between cognitive control deficits and problematic behavior such as antisocial behavior and substance use, but little is known about the predictive value of cognitive control for treatment outcome. The current study tests whether selected markers of baseline cognitive control predict (1) treatment completion of a day treatment program involving a combination of approaches for multi-problem young adults and (2) daytime activities a year after start of treatment, over and above psychological, social, and criminal characteristics. We assessed individual, neurobiological, and neurobehavioral measures, including functional brain activity during an inhibition task and two electroencephalographic measures of error processing in 127 male multi-problem young adults (aged 18-27 years). We performed two hierarchical regression models to test the predictive power of cognitive control for treatment completion and daytime activities at follow-up. The overall models did not significantly predict treatment completion or daytime activities at follow-up. However, activity in the anterior cingulate cortex (ACC) during response inhibition, years of regular alcohol use, internalizing problems, and ethnicity were all significant individual predictors of daytime activity at follow-up. In conclusion, cognitive control could not predict treatment completion or daytime activities a year after the start of treatment over and above individual characteristics. However, results indicate a direct association between brain activity during response inhibition and participation in daytime activities, such as work or school, after treatment. As adequate baseline inhibitory control is associated with a positive outcome at follow-up, this suggests interventions targeting cognitive control might result in better outcomes at follow-up.

Introduction

Problematic behavior such as antisocial behavior and substance use is a major cause of public concern, with implications for victims, perpetrators, and society (Moffitt, 2017). There is a growing body of literature on the efficacy of interventions aimed at reducing antisocial behavior (Bennett & Gibbons, 2000; Dodge & McCourt, 2010; Frick, 2016; Lipsey & Cullen, 2007; Reid & Gacono, 2000). However, the effectiveness of these interventions varies, as overall reoffending rates among juveniles and adults remain high even after treatment (Fazel & Wolf, 2015; van der Put et al., 2016) and treatment non-completion rates range from 20% to 40% (Rubin et al., 2007). Treatment programs tend to be more effective if they are individually tailored (Frick, 2016; Rubin et al., 2007), such as by detecting and treating early individual markers of treatment outcome. This approach is in line with the Risk-Need-Responsivity (RNR) model, which stresses the need for individually tailored interventions, and the specific treatment of factors known to be associated with successful reintegration of antisocial individuals (Andrews & Bonta, 2007; Andrews & Dowden, 2008; McRae, 2013; Polaschek, 2012). Therefore, more research on predictors of treatment outcome in antisocial populations is a promising approach to increasing treatment effectiveness and improving outcome results.

The biopsychosocial model offers a framework in the search for these predictors (Popma & Raine, 2006). This transactional model of antisocial behavior suggests that the interaction and joint contribution of biological, psychological, and social factors should be taken into account in the understanding and treatment of such behavior. During the past decades, research has shown that several individual characteristics are known to influence and predict treatment outcome, such as age, ethnicity and intelligence (Andrews & Dowden, 2006), psychopathy (Sewall & Olver, 2019), psychopathology (McCarter et al., 2016), differentiating between internalizing and externalizing psychopathology (Winters et al., 2008), aggression (Blader et al., 2013), impulsivity (Fishbein et al., 2009; Fornells et al., 2002), history of delinquency (Cottle et al., 2001; Lipsey & Cullen, 2007), and drug abuse (Lipsey & Cullen, 2007). However, many of the current prediction models have not been approached from a biopsychosocial perspective, and thus only few studies included both individual characteristics and neurobiological measures such as functional brain activity or electrophysiological measurements (Cornet et al., 2014; van der Gronde et al., 2014). Previous studies on neurobiological predictors of treatment outcomes in antisocial populations mainly focused on alterations in the autonomic nervous system (Alink et al., 2008; Beauchaine et al., 2000; Schechter et al., 2012; van der Gronde et al., 2014). Predictors of interest have included heart rate variability (Beauchaine et al., 2000), baseline heart rate (Ortiz & Raine, 2004), skin conductance level (van der Gronde et al., 2014), cortisol levels (Alink et al., 2008; Schechter et al., 2012), and testosterone levels (Schechter et al., 2012). Increased knowledge regarding neurobiological markers of treatment outcomes in antisocial behavior could aid in the tailoring of treatment and improve rates of treatment completion (Bootsman, 2018).

A vast body of literature provides evidence for an association between antisocial behavior and cognitive control. Cognitive control (also called executive control or executive functioning) is a multifaceted neuropsychological construct consisting of various top-down processes that are critical for goal-oriented and future-oriented behavior (Diamond, 2012; Gazzaley & D'Esposito, 2007; Sira & Mateer, 2014). It is argued that disruptions of cognitive control can lead to problematic behavior. Deficits in this higher order process could limit the possibility to adequately learn and adapt behavior in real world situations. Various deficits in cognitive control have been associated with antisocial behavior such as impaired performance on neuropsychological measures of executive functioning (Chamberlain et al., 2016; Ogilvie et al., 2011), an inability to restrain impulsive or inappropriate responses (Swann et al., 2009; Turner et al., 2018; Weidacker et al., 2017), an inability to detect and react to errors (Zeier et al., 2012), and abnormalities in neural regions associated with inhibitory control and the ability to flexibly adjust behavior (Aharoni et al., 2013; Guan et al., 2015; Sterzer, 2009; Yang & Raine, 2009; Zijlmans et al., 2019). However, little is known about the role of cognitive control as a predictor of treatment outcomes in antisocial or problematic populations. Previous research focused on the assessment of various components of executive functioning with neuropsychological tests (Aharonovich et al., 2003; Fishbein et al., 2009; Mullin & Simpson, 2007). Results from these studies indicate that cognitive control can predict treatment outcome, but they did not include neurobiological measures such as functional brain activity or event-related potentials (ERPs) during cognitive control-tasks. Using a biopsychosocial approach, behavioral measures (such as reaction time and accuracy) as well as neurobiological measures should be taken into account in the prediction of antisocial behavior, in addition to individual characteristics such as age, aggression and drug (ab)use. Previous studies in clinical populations indicate that the addition of neurobiological measures of cognitive control – specifically, two important indices: response inhibition and error processing – can aid in the prediction of substance abuse treatment outcome or recidivism (Aharoni et al., 2014; Aharoni, Vincent, Harenski, Calhoun, Sinnott-Armstrong, Gazzaniga, et al., 2013; Brewer et al., 2008; Luo et al., 2013; Marhe et al., 2013; Paulus et al., 2005; Steele et al., 2014). These studies suggest that associated neural correlates such as anterior cingulate cortex (ACC) activity and error-related brain potentials might function as biomarkers for those who are vulnerable to relapse or recidivism.

Response inhibition refers to the ability to suppress inappropriate behavior (Chambers et al., 2009), whereas error processing refers to the ability to detect and react to errors (Overbye et al., 2019). Both processes are critical for goal-oriented behavior in everyday life (Chambers et al., 2009; Overbye et al., 2019) and the discontinuation of maladaptive or impulsive behaviors such as substance abuse (Ivanov et al., 2008), pathological gambling (van Holst et al., 2012), and aggression (Sterzer, 2009). Aberrant response inhibition manifested in behavior (i.e., shorter reaction times and more errors) has been found in antisocial populations such as child sexual offenders (Turner et al., 2018) and psychopathic offenders (Weidacker et al., 2017). Furthermore, poor error processing at the behavioral level as measured with poor accuracy has been related to incarcerated offenders with antisocial personality disorder (Zeier et al., 2012). In addition to behavioral measures of cognitive control such as accuracy, reaction time, and errors, there are also neurobiological markers of cognitive control. Two neurobiological markers are event-related potentials (ERPs) and brain activity in specific regions of the (pre)frontal cortex during task performance. Converging evidence suggests activity in the ACC as a neural correlate of cognitive control (Nieuwenhuis et al., 2003) and specifically as a neural correlate of response inhibition (Aharoni, Vincent, Harenski, Calhoun, Sinnott-Armstrong, Gazzaniga, et al., 2013; Braver et al., 2001). Two electrophysiological indices of error processing are closely related: the error-related negativity (ERN) and error-related positivity (Pe) (Nieuwenhuis et al., 2001). The ERN is a negative potential that arises approximately 25-100 ms after an incorrect response (Bernstein et al., 1995) and is thought to reflect early, automatic error processing (Bernstein et al., 1995). In contrast, the Pe is a positive potential that follows the ERN and is thought to reflect the late, more conscious processing of an error (Luijten et al., 2011). Source localization studies have indicated that the ERN is most likely generated in the ACC and Pe amplitude has been correlated both negatively as well as positively to ACC activity (Edwards et al., 2012; Orr & Hester, 2012), suggesting an important role for the ACC, ERN, and Pe in cognitive control. Similarly, individuals with behavioral problems show altered activity of these specific correlates (Brazil et al., 2009; Carroll et al., 2015; Rüsch et al., 2010; Steele et al., 2016).

Regarding associations with populations demonstrating antisocial or impulsive behaviors, neuroimaging studies have shown reduced ACC activity during response inhibition and error processing in drug abusers (Hester et al., 2009), individuals with borderline personality disorder (Rüsch et al., 2010), and smokers with greater externalizing personality traits (Carroll et al., 2015). Additionally, two previous studies showed no difference on ERN, but reduced Pe amplitude in offenders compared with healthy controls (Brazil et al., 2009; Steele et al., 2016), implying that this population has intact early (automatic) error processing but aberrant late (more conscious) processing of an error. In contrast, a recent study found no difference in Pe amplitude, but reduced ERN in multi-problem young adults compared with healthy controls, implying aberrant early error processing (Zijlmans et al., 2019); same sample as current study). Although research on response inhibition and error processing has been rapidly growing, research on their prospective association with treatment outcomes in antisocial populations is scarce and results are mixed. Some literature examines neurocognitive predictors of treatment outcomes using electrophysiological indices of error processing in substance abusers (Marhe et al., 2013; Steele et al., 2014) and offenders (Steele et al., 2017). These studies showed that in adult substance abusers, there is an association between variation in ERN and Pe amplitude and treatment outcome (Marhe et al., 2013; Steele et al., 2014). More specifically, both improved error processing (larger Pe; (Steele et al., 2014)) and diminished error processing (reduced ERN; (Marhe et al., 2013; Steele et al., 2014)) have been predictive of treatment outcome. Additionally, real-world functioning outside of the treatment facility has also been studied. In the previously mentioned study on offenders, both reduced ACC activity and larger Pe amplitude were predictive of rearrests (Steele et al., 2017). Furthermore, prior studies have used blood-oxygen-level-dependent (BOLD) activation in the ACC to predict reoffense (Aharoni et al., 2014; Aharoni, Vincent, Harenski, Calhoun, Sinnott-Armstrong, Gazzaniga, et al., 2013) where changes in the brain hemodynamic response during a response inhibition task were predictive of rearrests following prison release. More specifically, the odds of rearrest were approximately double for offenders with relatively low ACC activity compared with offenders with relatively high ACC activity. These results suggest that neurobiological measures of cognitive control are plausible predictors of treatment outcome and real-world functioning (or real-world dysfunction such as reoffense). Despite these recent advances, the contribution of studies exploring the predictive value of neurobiological measures of cognitive control for treatment outcomes in populations displaying problematic behavior is limited and most studies fail to apply a biopsychosocial approach.

To our best knowledge, the predictive power of neurobiological and neurobehavioral indices of cognitive control for treatment outcomes, over and above psychological, social and criminal predictors, has not yet been studied in young adults facing multiple problems such as drug use and antisocial behavior. Furthermore, the current study is the first to include both functional magnetic resonance imaging (fMRI) activity of the ACC during response inhibition and ERP components during error processing to predict treatment outcomes. A sample of male multi-problem young adults is included at the start of multimodal (that is, involving a combination of approaches) day treatment program *De Nieuwe Kans* (DNK; translated as "New

Opportunities"). DNK provides a multimodal day treatment program for young adults facing a range of problems—for example, a history of delinquency, behavioral and psychological problems, no daytime activities (e.g., no work, education, other full-time activities), frequent substance use, and no or low income (Luijks et al., 2017; van Duin et al., 2017, 2018; Zijlmans et al., 2019). The main goal of DNK is to reintegrate participants into society by facilitating and retaining successful integration into education or employment and to increase self-sufficiency, and to subsequently reduce delinquency. The study has two aims: to test whether the selected markers of cognitive control, as measured at baseline, predict (1) treatment completion versus treatment dropout and (2) daytime activities a year after the start of treatment, over and above psychological, social and criminal characteristics of a multimodal day treatment program in multi-problem young adults. Examples of daytime activities a year after start of treatment are successful participation in education, work, or other full-time daytime activities such as voluntary work.

Methods and Materials

Participants

Participants were 127 male multi-problem young adults, ranging in age from 18 to 27 years (mean age = 21.92 years, SD = 2.40). They were recruited at the start of the day treatment program De Nieuwe Kans (DNK). Eight participants were excluded because of failure to complete the tasks, six participants were excluded because fewer than 6 error trials were usable for analysis (Olvet & Hajcak, 2009), and 8 participants did not start treatment after intake and were thus not enrolled in the multimodal day treatment program at DNK. These participants were also excluded from analysis. The final sample included 105 multi-problem young adults.

As the current study relies on previously collected data, no a priori sample size calculation could be performed for the current analysis. For the previously collected data, an a priori sample size calculation was performed that was based on a linear regression model (Zijlmans et al., 2018, 2019) whereas in the current study a logistic regression model is performed. With the expectation of a medium effect size, a power of 0.80, and an alpha of .05, we required a sample size of N = 103 for the EEG measurements (De Wied et al., 2011). Previous studies indicate a large effect size for similar fMRI-ACC measures (Fu et al., 2008; Rubia et al., 2001; van Holst et al., 2012). Thus, for the fMRI design, we performed a conservative power analysis with a medium effect size, a power of 0.80, and an alpha of .05. This resulted in a required sample size of 34 participants for the region of interest (ROI) analysis.

All procedures in the present study were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments, or comparable ethical standards. The study has been approved by the Medical Ethical Committee of the VU University Medical Center (registration number 2013.422 - NL46906.029.13) and all participants provided written informed consent. Participants received a reimbursement of 30 euros.

Treatment setting

The multimodal day treatment program at DNK was specifically designed to treat young male adults (18-27 years) with severe, multiple problems (e.g., drug use, psychological problems, antisocial behavior, and financial problems (van Duin et al., 2017)). By applying cognitive behavioral techniques, practical support, as well as education including sports, DNK aims to improve various facets of the participants life. The main goal of DNK is the guided reintegration into society, through continued participation in education or employment or other daytime activities after treatment.

Intervention

Participants at DNK receive group-oriented as well as individual-oriented treatment. The basis of this treatment is a multidimensional approach, in which all aspects of the participant's life are reviewed and included in the intervention to guide them through young adulthood. The intervention focuses on treating behavioral problems—in particular, antisocial behavior, and cognitive distortions, such as self-serving (antisocial) cognitions. Behavioral problems are treated by social workers and behavioral trainers through coaching, observation, one-on-one conversations, and cognitive behavioral therapy. Another goal of the intervention is to enhance self-sufficiency in several life domains such as housing, finances, social network, mental health, substance abuse, and daytime activities. This is achieved through various educational courses (e.g., sport, cooking, culture), cognitive behavioral therapy, individually tailored coaching, as well as through offering regularity and structure. After the option to share a breakfast, all classes start at 9:30 and end at 14:30 or 15:30 for 4 days per week. Typical duration of the intervention is 5 to 6 months, which ends with participants successfully obtaining education or employment, or receiving a referral to specialized (mental) health care. A referral to specialized care only occurred if the participant displayed very severe mental health or very severe abuse-related problems and with consent of the participant. If the participant ends the intervention prematurely and without consent from the trainers, this is defined as treatment dropout.

Predictors

Baseline variables were organized into four groups: (1) demographics and intelligence, (2) individual characteristics, (3), impulsivity, and (4) response inhibition and error processing.

The demographics and intelligence group consisted of ethnicity, education, and intelligence. The categorization of ethnicity was based on the Dutch definition of the *Centraal Bureau voor de Statistiek* (Statistics Netherlands) and included five categories: Western, Caribbean, Moroccan, Cape Verdean, and other non-western. The largest ethnic minority groups in Rotterdam are people of Surinamese, Turkish, Moroccan, Antillean, and Cape Verdean origin, with the Surinamese community being the smallest and the Cape Verdean community the largest (Crul et al., 2019). However, due to the relatively small number of Turkish, Surinamese, and Antillean ethnic backgrounds in the current sample, final categorization included Western, Caribbean (e.g. Antillean and Surinamese ethnicity), Moroccan, Cape Verdean, and other non-western (e.g., Turkish ethnicity). Education was categorized in primary only, junior secondary school, and senior secondary school. Intelligence was measured with four subscales of the Wechsler Adult Intelligence Scale third version (WAIS-III SF; digit symbol coding, information, block design, and arithmetic (Blyler et al., 2000)) resulting in an estimated IQ score.

The individual characteristics included history of delinquency, regular use of cannabis and alcohol in years, aggression, psychopathy, and psychopathology. Previous research has shown that these individual characteristics are known to influence and predict treatment outcome. History of delinquency was assessed as the number of past offenses registered in the Research and Policy database Judicial Documentation (OBJD) by the Research Documentation Center (WODC) of the Ministry of Security and Justice in the Netherlands. Drug and alcohol use were assessed with the Measurements in the Addictions for Triage and Evaluation Questionnaire (MATE; (Schippers et al., 2010)). Regular cannabis use was defined as the number of years of regular (i.e., weekly) cannabis use. Regular alcohol use was defined as the number of years of regular (i.e., weekly) alcohol use. Aggression was measured with the total score on the Reactive Proactive Aggression Questionnaire (RPQ: (Cima et al., 2013; Raine et al., 2006)). Psychopathy was assessed with the total score on the Youth Psychopathic Traits Inventory short version (YPI-sv; (Van Baardewijk et al., 2010)), and psychopathology was assessed with the Internalizing and Externalizing Problems score on the Adult Self-Report (ASR: (Achenbach & Rescorla, 2003)). The Internalizing Problems score included anxiety and depression, withdrawal, and somatic complaints. The Externalizing Problems score included rule-breaking and aggressive behavior, as well as other social problems.

Impulsivity

Impulse control was measured with the Dutch Barratt Impulsiveness Scale (BIS-11; (Lijffijt, 2005; Patton et al., 1995)), a self-report questionnaire measuring impulsivity. The total score was used as a predictor.

fMRI and behavioral measures of response inhibition

Response inhibition was measured with a Go/NoGo task previously used by Luijten et al., (2013). In short, participants are required to respond to vowels (i.e., Go trials) presented at 1 HZ, whilst refraining from responding when the presented letter is a repetition of the previous one (i.e., Nogo trials). In total 817 Go and 110 NoGo trials were presented. ACC activity during the commission errors versus correct hits contrast was assessed in an a priori defined ROI (14 mm radius-sphere at x = 3, y = 24, z = 33 (Aharoni, Vincent, Harenski, Calhoun, Sinnott-Armstrong, Gazzaniga, et al., 2013). All images were acquired with a 3T GE Healthcare MRI scanner (The Discovery® MRI 750 3.0T, Milwaukee, MN, USA). BOLD T2-weighed axial images were acquired with echo planar imaging in 42 slices with a repetition time (TR) of 2000 ms, echo time (TE) of 30 ms, flip angle (FA) of 80 degrees, field of view (FOV) 220 mm, and matrix size of 64 x 64 mm. A structural fast-spoiled gradient T1-weighted image was acquired in 180 sequential sagittal slices with a TR of 6.4 ms, TE of 2.8 ms, FA of 12 degrees, FOV of 240 mm, and the matrix size 240x240 mm. Imaging data were analyzed using Statistical Parametric Mapping 12 (SPM12: (Friston et al., 1994)). Preprocessing included the realignment and unwarping of all functional images. Next, the structural scan was coregistered to the mean T2*-weighted image and subsequently segmented. The images were normalized using the SPM T1-weighted MNI template and spatially smoothed with an 8-mm full-width half maximum Gaussian filter. The four conditions, NoGo correct, NoGo incorrect, Go correct, and Go incorrect were modeled and six movement parameters were added as covariates of no interest. ROI data for the ACC was extracted with the Marsbar toolbox for SPM (Matthew et al., 2002). Lastly, three behavioral outcome measures were collected, percentage correct trials for NoGo trials (i.e., accuracy NoGo trials), average reaction time on correct Go trials, and average reaction time on incorrect NoGo trials.

Electrophysiological and behavioral measures of error processing

Brain activity was recorded with a Biosemi ActiveTwo System amplifier to measure the EEG during an Eriksen-Flanker task previously used by Zijlmans et al., (2019). In short, participants responded to the middle letter in letter strings, HHHHH, SSSSS, HHSHH, SSHSS, by pressing the corresponding letter on the keyboard with their left or right index finger. Each string was presented for 52 ms, the maximum response time was 648 ms, and a stimulus was shown once every 1450 ms. In total 400 trials were presented per participant. Silver chloride (Ag/AgCl) electrodes were placed upon the scalp according to the International 10-20 System, with two reference electrodes on the left and right mastoids. A sampling rate of 512 Hz and 24-bit analogue-to-digital conversion was used to digitize the signals. Offline filtering was done using a low cutoff of 0.15 Hz and a high cutoff of 30 Hz (24 dB/octave slope). To control for ocular artifacts, the vertical and horizontal electro-oculogram were assessed. Additional artifact rejection (100 µV) was performed automatically. The -100–0 ms preresponse period served as baseline.

Error processing was measured with the response-locked ERN and Pe. For both indices, difference waves in mean activity across response conditions (incorrect minus correct) were calculated in a priori time intervals. The ERN was defined as the error-minus correct difference wave in a 25–100 ms time window on the FCz electrode. The Pe was defined as the difference wave in a 250–400 time window on the Pz electrode. This was based on previous approaches typically used in ERN/Pe research (Brazil et al., 2009; Hajcak et al., 2005; Marhe et al., 2013; Olvet & Hajcak, 2008; Zijlmans et al., 2019). Lastly, four behavioral outcome measures were collected, average reaction time for correct and incorrect trials, accuracy for total trials, and post error slowing effect (i.e., mean reaction time post error minus mean reaction time post correct response).

Outcome measures

Outcome was assessed with two measures. The first outcome measure was treatment completion versus dropout as defined by DNK. DNK considered the treatment a success if the participant enrolled in education or employment, or if needed, if the participant was referred to specialized (mental) health care. According to DNK, a referral was an appropriate ending of the treatment, since they recognized and anticipated the specialized needs of the participant that could not be met at DNK itself. Treatment dropout was defined as dropout before finalizing the treatment and thus before enrollment in education or employment, or referral to specialized care, without mutual agreement between DNK and the participant. The second outcome measure was daytime activity versus no daytime activity a year after start of treatment at follow-up. Daytime activity was defined as part-time or full-time education, part-time or full-time employment, or other full-time daytime activities, such as full-time care for others, a sports membership, voluntary work, participation in a treatment program, internships or starting one's own business. It was possible for a participant to have more than one daytime activity. The different forms of daytime activities were used for the descriptive statistics but not for analysis. A dichotomous variable for daytime activity (yes/no) was created and used for data analysis.

Procedure

Data were collected by trained research assistants at the start of the treatment within the first 2 weeks (baseline) and 14 months later (follow-up). For the baseline measurement, questionnaires were administered in a maximum of two sessions in a period of two weeks, independent of the EEG and fMRI measurements. EEG measurements were assessed in one session at the Erasmus University Rotterdam, in the Erasmus Behavioral Lab of the Institute for Psychology. Participants were seated in a comfortable chair in a sound-attenuated room with dimmed lights. After explanation of the task by a trained researcher, participants started with a practice trial, followed by the experiment. The fMRI measurements were assessed in a different session than the EEG, in the Erasmus Medical Center Rotterdam. Participants received explanation from a trained researcher. The experiment started after a practice trial. The first outcome measure (treatment completion versus dropout) was registered by employees of DNK, at the end of treatment. The second outcome measure (daytime activities) was measured by research assistants at follow-up, 14 months after start of the treatment. For the follow-up measurement participants were contacted by phone, email, social media platforms, e.g., Facebook and WhatsApp or by means of a house visit. The assessment was done either by phone, at DNK, or at a public place (in the latter case there were always two researchers present for safety purposes).

Data analysis

To account for missing values (8.3% in total), multiple imputation for predictors with a maximum missingness of 30% was applied to impute to 30 complete sets (White et al., 2011). Little's Missing Completely At Random (MCAR) test was employed; the data were MCAR (x^2 = 100.223, *df* = 107, *p* = .66). Logistic regressions were employed to assess the predictive value of background, behavioral, and neurobiological factors on the two treatment outcome measures, completion versus dropout and daytime activity versus no daytime activity at follow up. The predictor variables were tested for normality of distribution, linearity, multicollinearity, and independence of errors. Box–Tidwell transformations were used to test the assumption of linearity between the continuous predictors and the logit of the dependent variables. Linearity was not violated. In addition, multicollinearity was tested by inspecting variance inflation factors (VIF). VIF values greater than 10 indicate a multicollinearity problem (Myers, 1990). Most VIF values did not exceed 10 except for average reaction time on correct Flanker trials and average reaction time on incorrect Flanker trials. As both variables measure reaction time on the Flanker task, it is not uncommon to discover dependency between these variables. However, these results should still be interpreted with caution. Lastly, independence of errors was tested by looking at the residuals. This assumption was not violated. A Western ethnic background and primary education only were used as reference indicators for the categorical variables. Two hierarchical regression analyses were applied to examine the predictive power of the behavioral and neurobiological variables over and above the demographic variables and the individual characteristics. The predictors were forced into the model in the following sequence: (1) demographics and intelligence, (2) individual characteristics, (3) impulsivity, and (4) response inhibition and error processing. The level of significance was set at *p* = .05. The results section will first report the descriptive statistics, then the outcome of the logistic regression on treatment completion versus dropout, and lastly the outcome of the logistic regression on daytime activities versus no daytime activities. Individual contribution of the predictors per logistic regression were also examined.

Results

Group-level average ERPs and fMRI activation patterns are displayed in Figure 1. Descriptive statistics (*M*, *SD*, *%*) of all predictor variables are shown in Table 1.

Table 1 Descriptives of all predictors

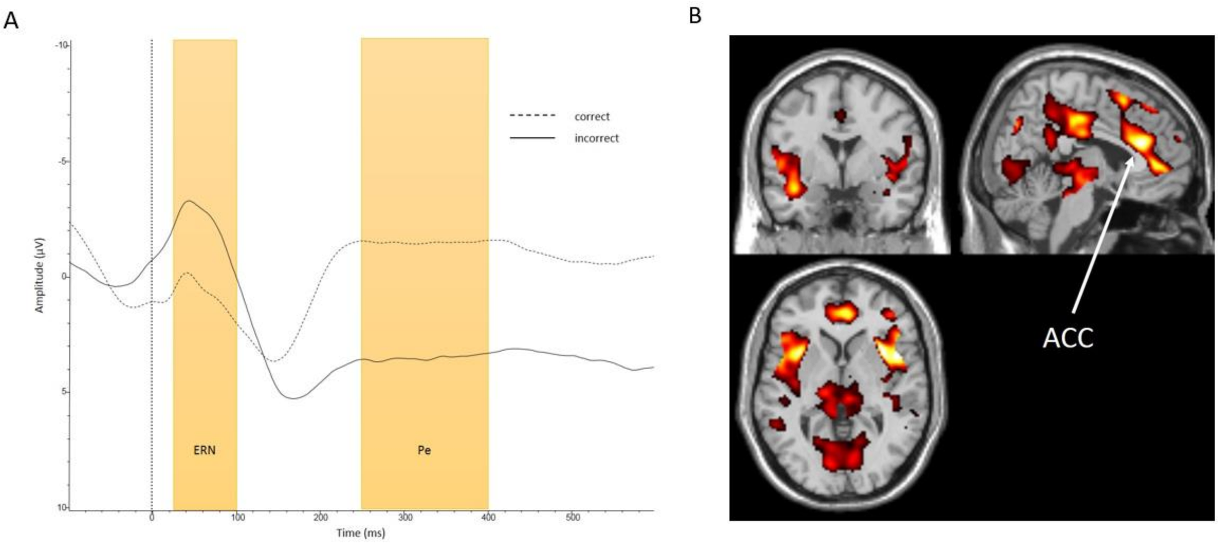
Variable	*Mean / N*	*SD / %*
Ethnicity	18	17.1
Caribbean	41	39.0
Moroccan	20	19.0
Cape Verdean	7	6.7
Other non-Western	19	18.1
Education		
Primary only	46	43.8
Junior secondary	38	36.2
Senior secondary	21	20.0
IQ	82.35	9.81
Number of past offenses < treatment start	4.52	4.48
Regular use of cannabis in years	4.32	3.79
Regular use of alcohol in years	2.32	3.65
RPQ total	16.39	7.66
ASR Internal	72.52	24.18
ASR External	69.22	23.83
YPI-sv total	33.10	7.83
BIS-11 total	64.14	8.90
ACC activity during response inhibition	2.87	2.42
Reaction time GO trials	409.92	53.65
Reaction time NOGO trials	392.34	81.55
Accuracy NOGO trials	.50	0.16
ERN Flanker task	-4.85	4.65
Pe Flanker task	5.82	5.20
Reaction time correct Flanker trials	450.33	74.05
Reaction time incorrect Flanker trials	406.07	76.01
Accuracy Flanker trials	.81	0.16
Post error slowing effect	43.02	38.49

Note. IQ = intelligence quotient; RPQ = Reactive Proactive Questionnaire; ASR = Adult Self Report; YPI-sv = Youth Psychopathic Traits Inventory short version; BIS-11 = Barratt's Impulsivity Scale; ACC = anterior cingulate cortex; ERN = error-related negativity; Pe = error positivity. N = 105 for all variables

Outcome measures

Directly posttreatment, 61 (58.0%) participants were successfully enrolled into either education (17.1%) or work (29.5%), or referred to other care (11.4%). Information on treatment success or failure was missing for one participant. The remaining 43 (41.0%) participants were dropouts.

Figure 1 A. Electroencephalographic waveforms in response to correct and incorrect trials. ERN = error-related negativity; Pe = error positivity. **B.** Whole brain family wise error corrected hemodynamic activity during the commission errors vs. correct hits contrast, x = 49, y = 64, z = 38. ACC = anterior cingulate cortex.



A year after start of treatment, 93 participants responded to the follow-up assessment. Twelve participants were lost to attrition. A total of 49 (46.7%) participants had found one or more daytime activities, of which 12 participants were previously classified as treatment dropouts. An overview of the different daytime activities can be found in Table 2. On average, participants remained in treatment for 171.88 days until treatment success (N = 61) or 121.08 days until treatment dropout (N = 43).

Table 2 Overview of daytime activities a year after start of treatment

Daytime activities	N	%
Work	26	24.8
Education	18	17.1
sports membership	7	6.7
Care for others	4	3.8
Treatment program	5	4.8
Voluntary work	6	5.7
Other	5	4.8
No daytime activity	44	41.9
Non-response	12	11.4

Note. N = 105

Results of the first hierarchical regression predicting treatment completion versus dropout are shown in Table 3. The model containing only demographics and intelligence (x^2 = 0.709, *df* = 7, *p* = .664) did not significantly predict treatment outcome. Adding the individual characteristics did not significantly improve the model (x^2 = 0.628, *df* = 14, *p* = .844) nor did adding impulsivity (x^2 = 0.639, *df* = 15, *p* = .844).

Table 3 Results of hierarchical regression predicting treatment outcome

				95% CI *B*	
	B	*SE (B)*	*p*	Lower	Upper
Block 1					
Constant	.693	2.009	.730	.039	102.688
Western	Ref.				
Caribbean	.314	.608	.605	.416	4.505
Moroccan	-.469	.667	.482	.169	2.313
Cape Verdean	1.736	2455.936	.999	.000	.
Other non-Western	.313	.709	.659	.341	5.495
Primary only	Ref.				
Junior secondary	-.555	.568	.328	.189	1.745
Senior secondary	.047	.471	.921	.417	2.635
IQ	-.005	.022	.839	.953	1.040
Constant					
Western	Ref.				
Caribbean	.693	2.009	.730	.039	102.688
Moroccan	Ref.				
Cape Verdean	.314	.608	.605	.416	4.505
Other non-Western	-.469	.667	.482	.169	2.313
Primary only	1.736	2455.936	.999	.000	.
Junior secondary	.313	.709	.659	.341	5.495
Senior secondary	Ref.				
Block 2					
Constant	.749	2.410	.756	.019	237.910
Western	Ref.				
Caribbean	.208	.657	.751	.340	4.465
Moroccan	-.880	.740	.234	.097	1.770
Cape Verdean	1.917	2303.193	.999	.000	.
Other non-Western	.261	.740	.724	.304	5.540
Primary only	Ref.				
Junior secondary	-.489	.598	.414	.190	1.982
Senior secondary	.035	.499	.945	.389	2.756
IQ	.007	.024	.771	.961	1.055
History of delinquency	.023	.053	.659	.923	1.135
Regular use of cannabis in years	.036	.068	.598	.907	1.185
Regular use of alcohol in years	-.128	.075	.087	.760	1.019
RPQ total	-.003	.034	.926	.933	1.066
ASR Internal	.004	.012	.771	.979	1.028
ASR External	-.010	.014	.478	.963	1.018
YPI-sv total	-.011	.035	.762	.923	1.060
Block 3					
Constant	1.822	.2697	.499	.031	1222.183
Western	Ref.				
Caribbean	.197	.661	.766	.333	4.443
Moroccan	-.982	.755	.194	.085	1.647
Cape Verdean	1.891	2309.875	.999	.000	.
Other non-Western	.198	.744	.790	.284	5.235

Table 3 (continued)

				95% CI *B*	
	B	*SE (B)*	p	Lower	Upper
Primary only	Ref				
Junior secondary	-.602	.619	.331	.163	1.842
Senior secondary	.018	.502	.972	.381	2.722
IQ	.009	.024	.720	.962	1.057
History of delinquency	.031	.054	.563	.928	1.146
Regular use of cannabis in years	.036	.068	.594	.907	1.186
Regular use of alcohol in years	-.138	.076	.071	.750	1.012
RPQ total	-.003	.034	.928	.932	1.066
ASR Internal	.004	.012	.722	.980	1.029
ASR External	-.005	.015	.731	.966	1.024
YPI-sv total	-.001	.038	.982	.928	1.076
BIS-11 total	-.029	.034	.379	.909	1.037
Block 4					
Constant	1.556	3.578	.664	.004	5269.558
Western	Ref.				
Caribbean	-.093	.798	.907	.191	4.355
Moroccan	-1.359	.840	.106	.050	1.332
Cape Verdean	2.043	1921.328	.999	.000	.
Other non-Western	.081	.863	.925	.200	5.886
Primary only	Ref.				
Junior secondary	-.641	.687	.351	.137	2.025
Senior secondary	.102	.563	.856	.367	3.339
IQ	.003	.030	.926	.946	1.063
History of delinquency	.057	.064	.368	.935	1.200
Regular use of cannabis in years	.044	.081	.592	.891	1.225
Regular use of alcohol in years	-.174	.090	.052	.705	1.002
RPQ total	-.007	.038	.863	.922	1.071
ASR Internal	.003	.014	.829	.975	1.032
ASR External	-.007	.016	.781	.964	1.028
YPI-sv total	-.004	.044	.930	.913	1.087
BIS-11 total	-.028	.038	.466	.904	1.047
ACC activity during response inhibition	.156	.129	.229	.907	1.506
Average RT GO	.000	.001	.558	.998	1.001
Average RT NOGO	.000	.001	.886	.999	1.001
Accuracy NOGO	1.576	2.100	.453	.078	298.998
ERN Flanker	.006	.068	.929	.881	1.149
Pe Flanker	-.016	.063	.801	.870	1.113
Average RT correct Flanker	.012	.013	.352	.986	1.039
Average RT incorrect Flanker	-.009	.012	.451	.969	1.014
Total accuracy Flanker	-.722	3.587	.841	.000	550.019
Post error slowing	.005	.009	.634	.986	1.023

Note. Nagelkerke’s R2 for block 1 = .064, Nagelkerke’s R2 for block 2 = .062, Nagelkerke’s R2 for block 3 = .133, Nagelkerke's R2 for block 4 = .209

Table 4 Results of hierarchical regression predicting daytime activity

				95% CI *B*	
	B	*SE (B)*	p	Lower	Upper
Block 1					
Constant	-.493	2.163	.820	.009	42.342
Western	Ref.				
Caribbean	-.326	.658	.620	.199	2.619
Moroccan	-1.965	.803	.014	.029	.677
Cape Verdean	-1.553	1.050	.139	.027	1.657
Other non-Western	-.269	.744	.718	.178	3.287
Primary only	Ref.				
Junior secondary	.658	.632	.298	.559	6.671
Senior secondary	.588	.508	.247	.665	4.876
IQ	.010	.024	.666	.964	1.060
Constant					
Western	-.493	2.163	.820	.009	42.342
Caribbean	Ref.				
Moroccan	-.326	.658	.620	.199	2.619
Cape Verdean	-1.965	.803	.014	.029	.677
Other non-Western	-1.553	1.050	.139	.027	1.657
Primary only	-.269	.744	.718	.178	3.287
Junior secondary	Ref.				
Senior secondary	.658	.632	.298	.559	6.671
Block 2					
Constant	-1.943	2.914	.505	.000	43.304
Western	Ref.				
Caribbean	-.329	.761	.665	.162	3.197
Moroccan	-2.582	.953	.007	.012	.490
Cape Verdean	-1.550	1.145	.176	.022	2.004
Other non-Western	-.226	.849	.790	.151	4.212
Primary only	Ref.				
Junior secondary	.719	.684	.293	.537	7.852
Senior secondary	.716	.572	.210	.667	6.276
IQ	.027	.028	.334	.973	1.085
History of delinquency	-.034	.072	.641	.839	1.114
Regular use of cannabis in years	.131	.085	.121	.966	1.346
Regular use of alcohol in years	.-1.42	.085	.095	.734	1.025
RPQ total	-.030	.040	.458	.898	1.050
ASR Internal	.035	.015	.018	1.006	1.065
ASR External	-.026	.017	.117	.943	1.007
YPI-sv total	-.005	.041	.895	.918	1.078
Block 3					
Constant	-.312	3.174	.922	.001	368.065
Western	Ref.				
Caribbean	-.393	.772	.610	.148	3.066
Moroccan	-2.777	.980	.005	.009	.425
Cape Verdean	-1.618	1.151	.160	.021	1.893
Other non-Western	-.407	.865	.638	.122	3.627

Table 4 (continued)

				95% CI *B*	
	B	*SE (B)*	p	Lower	Upper
Primary only	Ref.				
Junior secondary	.604	.702	.390	.462	7.245
Senior secondary	.678	.579	.242	.633	6.130
IQ	.032	.029	.262	.976	1.092
History of delinquency	-.025	.074	.737	.844	1.127
Regular use of alcohol in years	-.152	.086	.077	.725	1.017
RPQ total	-.029	.040	.467	.897	1.051
ASR Internal	.038	.015	.012	1.008	1.069
ASR External	-.019	.018	.284	.948	1.016
YPI-sv total	.011	.045	.799	.926	1.105
BIS-11 total	-.050	.040	.207	.879	1.028
Block 4					
Constant	1.844	4.797	.701	.001	77018.97
Western	Ref.				
Caribbean	-1096	1.070	.306	.041	2.728
Moroccan	-4.005	1.399	.004	.001	.283
Cape Verdean	-.956	1.391	.492	.025	5.866
Other non-Western	-.678	1.236	.583	.045	5.722
Primary only	Ref.				
Junior secondary	.646	.912	.479	.319	11.403
Senior secondary	1.223	.769	.112	.752	15.351
IQ	.033	.039	.406	.956	1.116
History of delinquency	.063	.102	.540	.871	1.301
Regular use of cannabis in years	.192	.118	.105	.961	1.527
Regular use of alcohol in years	-.258	.126	.041	.603	.989
RPQ total	-.061	.053	.249	.849	1.044
ASR Internal	.054	.022	.014	1.011	1.102
ASR External	-.022	.022	.304	.937	1.020
YPI-sv total	-.004	.065	.951	.876	1.132
BIS-11 total	-.039	.056	.494	.861	1.075
ACC activity during response	.408	.183	.026	1.050	2.155
Average RT GO	.000	.001	.687	.998	1.003
Average RT NOGO	-.001	.001	.231	.997	1.001
Accuracy NOGO	1.451	2.737	.596	.020	918.518
ERN Flanker	.100	.099	.308	.911	1.342
Pe Flanker	.083	.093	.368	.906	1.304
Average RT correct Flanker	.036	.020	.072	.997	1.078
Average RT incorrect Flanker	-.033	.018	.062	.934	1.002
Total accuracy Flanker	-5.988	5.062	.237	.000	51.249
Post error slowing	.006	.013	.628	.981	1.033

Note. Nagelkerke's R^2 for block 1 = .156, Nagelkerke's R^2 for block 2 = .312, Nagelkerke's R^2 for block 3 = .332, Nagelkerke's R^2 for block 4 = .518

The overall model containing all predictors including error processing and response inhibition did not significantly predict treatment outcome (x^2 = 0.502, *df* = 25, *p* = .981). Controlling for all other predictors, none of the individual predictors reached significance.

Results of the second hierarchical regression predicting daytime activity versus no daytime activity at follow-up are shown in Table 4. The model containing only demographics and intelligence (x^2 = 1.654, *df* = 7, *p* = .115) failed to reach statistical significance, as did the models including individual characteristics (x^2 = 1.695, *df* = 14, *p* = .052) and impulsivity (x^2 = 1.701, *df* = 15, *p* = .064). The overall model including error processing and response inhibition also did not significantly predict whether the participant engaged in a daytime activity at follow-up (x^2 = 1.519, *df* = 25, *p* = .059). However, when controlling for all other predictors, the ACC activity during the Go/NoGo contrast (*p* = .026, odds ratio = 0.408), regular alcohol use in years (*p* = .041, odds ratio = -0.258), the Internalizing Problem Score on the ASR (*p* = .014, odds ratio = 0.054) and a Moroccan ethnic background versus Western ethnic background (*p* = .004, odds ratio = -4.005) all significantly predicted whether a participant engaged in a daytime activity. In other words, increased ACC activity during response inhibition, decreased years of regular alcohol use, and an increased score on internalizing problems all resulted in higher odds on daytime activity. In addition, participants with a Moroccan ethnic background had lower odds on daytime activity at follow-up compared with participants with a Western ethnic background. Note that a Moroccan ethnic background vs. Western ethnic background and the Internalizing Problem Score were also significant in the previous blocks (1, 2, 3). In contrast, regular alcohol use in years only reached significance in the last block.

Discussion

The present study addressed the predictive value of neurobiological and neurobehavioral measures of cognitive control in relation to multi-problem young adults' treatment completion and engagement in daytime activities at follow-up. The results of the overall models showed that individual characteristics (psychological, social, criminal) were not associated with treatment completion or daytime activities at follow-up. Most pertinent to this study, is that the addition of error processing and response inhibition did not change the results, meaning that both the original model and the complete model containing the neurobiological and neurobehavioral measures of cognitive control did not reach significance. However, when controlling for all other predictors, activity in the ACC during response inhibition, regular use of alcohol in years, internalizing problems, and ethnicity all significantly predicted whether a participant engaged in a daytime activity.

In the current paper, cognitive control was not associated with treatment completion versus dropout. This is in line with a study amongst aggressive forensic psychiatric outpatients, where behavioral response inhibition could not distinguish between treatment completers and dropouts (Smeijers et al., 2018). Likewise, in a study in substance abusers (Moriyama et al., 2002), treatment effectiveness (e.g., resumed substance use after treatment or not) could not be predicted with neuropsychological tests of cognitive control. As opposed to these studies and the current results, aberrant error processing as indicated by a smaller ERN (Marhe et al., 2013) and a larger Pe (Steele et al., 2017) has been previously predictive of treatment completion in adult substance abusers. One explanation for the difference in results on error processing might be the difference in patient population. The current heterogeneous population suffered from a plethora of problems of varying severity, including but not limited to history of delinquency, behavioral and psychological problems, no daytime activities, frequent substance use, and no or low income (Luijks et al., 2017; van Duin et al., 2017, 2018; Zijlmans et al., 2018, 2019). It is possible that aberrant error processing reflects a deficit in substance users and thus efficiently discriminates between substance abusers and non-abusers in treatment outcome, but this effect does not apply to heterogeneous populations such as the current sample. Another possible explanation may be the difference in age, as the current study focused on young adults, rather than adults. Some research suggests the Pe increases with age (Grammer et al., 2014), although other studies do not support these findings (Davies et al., 2004; Santesso et al., 2006). Likely, the age range of the participants in the current study was too small to establish any age-related differences, thus studies including more age-related heterogeneity are warranted to uncover such effects.

Notwithstanding the result of the overall model failing to predict daytime activity at follow-up, we found a direct association with ACC activity during a response inhibition task. Increased ACC activity during response inhibition was associated with higher odds of involvement in daytime activities one year after start of treatment. This suggests that adequate inhibitory control (Kerns et al., 2004) at baseline is associated with a positive outcome (e.g., participation in daytime activities) a year later at follow-up. This is in line with a previous study, where increased ACC activity has been related to lower instance of rearrests in adult offenders (Aharoni, Vincent, Harenski, Calhoun, Sinnott-Armstrong, S, et al., 2013). It might therefore be beneficial to increase cognitive control by means of interventions that modulate ACC activity. This in turn could lead to better outcomes. Previous studies suggest a positive effect of physical activity on cognitive control, through increased neural efficiency (Erickson et al., 2015) in the prefrontal cortex and ACC (Voss et al., 2011). Furthermore, a reduction in ACC activity is related to better treatment engagement (Devito et al., 2017). It is thus possible that interventions targeting ACC activity, for example through physical activity, could potentially increase neural efficiency (thus reducing activity) in cognitive control-related regions, and subsequently improve cognitive control. This could in turn result in more positive outcomes at follow-up, but more longitudinal studies are needed to explore this.

The question arises as to why the current measurements of cognitive control failed to predict treatment completion versus dropout, yet ACC activity during response inhibition (a marker of cognitive control), did predict participation in daytime activities at follow-up. It is possible that higher-level cognitive abilities such as response inhibition and error processing are more important for retaining, rather than acquiring, successful reintegration into society. This could be due to the diminishing degree of guidance as time elapses. As treatment completion is measured in terms of reentry into society through the means of education or work, the intervention facilitates and structures this transition as much as possible. However, after treatment completion or dropout, the facilitation and structure of the intervention are discontinued and participants have to rely more on their individual abilities, such as cognitive control. This could explain why some measurements of cognitive control, such as ACC activity during response inhibition, are more sensitive to predicting daytime activities at follow-up than to predicting treatment completion directly posttreatment. Better aftercare or more tailored aftercare, for example, more structured aftercare for participants with less cognitive control, could possibly aid participants in retaining successful reintegration into society through continued participation in daytime activities.

Besides brain activity during response inhibition, more years of regular (i.e., weekly) alcohol use was also related to lower odds on daytime activity participation at follow-up. Regular alcohol use impairs inhibition and judgment (Lee & Snape, 2008) which could result in socially undesirable behavior or other forms of social dysfunction, diminishing the likelihood to acquire or retain daytime activities. This is supported by a prospective cohort study in adults relating high alcohol consumption and problem drinking to adverse labor market transitions, such as a lower chance of finding a new job after being unemployed as well as a higher chance of becoming unemployed (Jørgensen et al., 2019). Similarly, another study in young university students found an association between high levels of alcohol consumption and low academic performance as well as low mental health outcomes (Tembo et al., 2017). In short, these findings suggest that regular alcohol use has a negative impact on daytime activities such as work and school.

Additionally, internalizing, but not externalizing problems at baseline were associated with daytime activities at follow-up. This is partly in line with previous literature, where both increased internalizing and externalizing problems were related to negative outcomes such as poorer work performance and poorer academic achievement (Korhonen et al., 2018; Mordre et al., 2012; Narusyte et al., 2017). In contrast, the current study found an association between greater internalizing problems and a positive outcome (i.e., better odds on daytime activity). Internalizing problems such as depression and anxiety are covert, often overlooked behaviors (Miller & Jome, 2010), especially in young adults with comorbid externalizing problems (Hankin et al., 2016). Internalizing problems are therefore sometimes described as a secret illness (Reynolds, 1992). In contrast, externalizing problems are mostly overt and more easily detected behaviors due to their disruptive nature (Forns et al., 2011). It may be that participants with more severe or pronounced internalizing problems showed less externalizing behavior. This is supported by studies suggesting internalizing problems could act as a constraining factor in the development of externalizing behavior, possibly related to withdrawal or inhibition (Masten et al., 2005; Mesman et al., 2001; Moffitt et al., 2002). Speculatively, it is also possible that individuals with more severe or obvious internalizing problems were treated more leniently regarding their disruptive behavior, causing them to acquire and retain more daytime activities than those with less internalizing problems.

Lastly, participants with a Moroccan ethnicity had lower odds on daytime activities compared with participants with a Western ethnicity. In line with this result, persons of Moroccan origin are often represented as the ethnic group with the least adequate reintegration into the Dutch society (Dagevos et al., 2003; Roggeband & van der Haar, 2018) compared to other ethnic minorities. Moreover, participants of Moroccan ethnicity face more problems compared with higher perceived discrimination (Dagevos et al., 2003; Roggeband & van der Haar, 2018), and more negative stereotyping (Van Craen et al., 2007). Thus, it is plausible that Moroccan migrants are more sensitive to certain treatment characteristics, such as sharing of worldview, empathy, expertise, and ethnic matching in caregivers and participants (Knipscheer & Kleber, 2004). The current study did not include such treatment characteristics in the analysis, thus future studies should examine their possible effect on the association between daytime activities and cognitive control in different ethnic groups.

A relatively large number of predictors were used in the current study which could explain why most of the individual measures did not reach significance, except for ACC activity, regular alcohol use in years, internalizing problems, and ethnicity. Nonetheless, the current predictors were included because the model adopted a biopsychosocial model in which the joint contribution of various predictors was examined. It is also possible that treatment characteristics, such as the combination of techniques from cognitive-behavioral therapy (CBT) and practical support play a role in this relationship. It is assumed that successful use of CBT relies on the adequate use of cognitive control (James et al., 2008; Goodkind et al., 2016; Mohlman & Gorman, 2005), but the association with other forms of intervention, such as practical support or lessons, remains unclear. Therefore, it is possible that the current multimodal treatment relies on a combination of cognitive control and individual abilities such as treatment motivation (Walton, 2015). This could imply that cognitive control is only associated with treatment outcome when controlling for additional individual abilities, or that cognitive control is not associated with the current multimodal treatment. The current study included other relevant individual characteristics such as psychological state and IQ, but did not include individual treatment characteristics such as treatment motivation. Future studies should include other individual characteristics to uncover any effect of the individual on the association with treatment outcome.

The current study is not without limitations. Firstly, self-report questionnaires were used to measure the individual characteristics of the participants, and thus their answers could be biased or completed in a socially desirable manner. Secondly, the low average IQ of the current sample (mean = 82) and low average educational level (20% finished secondary school) could influence the results due to lack of understanding of the tests, although post-hoc analysis revealed no relationship between IQ and any of the predictors or outcome measures. Thirdly, due to small sample sizes per activity, the current study did not distinguish between the different types of daytime activities. Future research should replicate this study with larger sample sizes, to determine any effect of the type of activity on cognitive control. Previous research has established the critical role of cognitive control in education and work (e.g., Diamond 2013) yet for other daytime activities such as sports membership or caring for others this remains unclear. It is thus possible that different types of daytime activities require different amounts of cognitive control, resulting in different outcomes. Lastly, DNK considered the treatment as completed after enrollment in education or employment, or after referral to appropriate (mental) health care. A referral to health care could be seen as a different outcome compared to education and employment, which could possibly threaten the generalizability of the current study. However, the main goal of the treatment was participation in education or employment. A referral to specialized care only occurred if the participant displayed too severe mental health or too severe abuse-related problems and with consent of the participant. If a participant received a referral, the treatment at the current intervention was (temporarily) discontinued, thus the treatment was seen as completed. Future research could also focus on children, adolescents, and adults simultaneously to distinguish any age-related effect on the association with cognitive control and treatment outcome, as it is possible that different age-groups display a different relation between cognitive control and treatment outcome. Another recommendation could be to monitor and distinguish the amount of aftercare participants receive (e.g., from the intervention, work, or education), to examine if this could explain different associations of cognitive control directly post-treatment versus at follow-up. Lastly, other approaches might be able to examine whether cognitive control has a population-related association with a substance abuse population by comparing the effect of cognitive control in a substance abuse population versus other populations showing externalizing problems such as antisocial behavior.

Biomarkers (including neurobiological markers) provide objective and measurable indices which could aid in the individualization of treatment and the prediction of antisocial behavior. However, several ethical concerns have been raised about the use of such markers for the prediction of antisocial behavior (Jurjako et al., 2018). These include the extrapolation of group-level information to gain knowledge on an individual level (Dawid, 2017), large error margins in risk estimates (Monahan, 2014), differences in the conceptualization of behavior between the legal system and science (Buckholtz & Faigman, 2014; Francken & Slors, 2018), and the heterogeneous, symptomatic conceptualization of most psychiatric disorders (Jurjako et al., 2018). First, the legal system is mostly interested in individual propensities whereas scientific research commonly uses group average data. The use of information on group level could obscure detection of individual differences, which could lead to biases. Second, the relatively large error margins in risk-assessment tools lower the certainty for an individual's propensity for future violent behavior. Third, legal constructs are often prone to different conceptualizations than those used in biological processes. This could lead to wrong impressions about reliability and relevance of the biomarker-information, as not all legal constructs are directly transposable to the biological processes. Lastly, most psychiatric disorders are conceptualized as heterogeneous dimensional constructs. This current taxonomy relies mostly on behavior and, just as with the legal constructs, not all behavior is transposable to biological processes, which could affect the predictive value of biomarkers on their own. This is in line with the biopsychosocial model in which combinations of biological, psychological, and social factors should be taken into account in the prediction of antisocial behavior (Popma & Raine, 2006). Jurjako et. al conclude that these issues are important to consider, but they do not argue against the use of biomarkers in the prediction of antisocial behavior; rather they advise to take caution when using biomarkers (Jurjako et al., 2018).

In conclusion, the overall models containing cognitive control as measured by neurobiological and neurobehavioral factors did not predict treatment completion or daytime activities at follow-up in multi-problem young adults. However, ACC activity during a response inhibition task did predict daytime activities when controlling for other measurements of cognitive control and individual characteristics, suggesting a possible role for inhibitory control.

CHAPTER 3

Distinguishing between primary and secondary self-serving cognitive distortions in the association with antisocial behavior and the possible role of error processing

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Abstract

Previous research has linked pro-criminal attitudes (e.g., distortions in thinking patterns) to antisocial behavior, yet few studies examined if specific biases relate differently to specific antisocial behaviors. Therefore, the current study examined the unique relationships between self-serving cognitive distortions (i.e., self-centeredness, blaming others, minimizing/mislabeling, assuming the worst) and antisocial behaviors (i.e., antisocial personality behavior, proactive and reactive aggression, number of criminal offenses) in young adults displaying multiple problems including antisocial behavior. Additionally, we explored the possible moderating role of cognitive control, i.e., error-related negativity during error processing. Results showed significant positive relationships between self-centeredness with antisocial personality behavior and with proactive and reactive aggression. No other associations were uncovered. The error-related negativity did not moderate any of these associations, suggesting individual differences in error processing do not yield different antisocial outcomes. This indicates the need for addressing specific pro-criminal attitudes, specifically self-centeredness, rather than treating them as one general antisocial bias, however not through interventions enhancing error processing.

Introduction

Antisocial behavior represents a collection of disruptive behaviors violating legal and moral rules, including delinquency and aggression (Moffitt, 2017). The efficacy of current interventions aimed at reducing such behavior varies, with the most promising interventions reducing recidivism by 40% (Lipsey & Cullen, 2007; Rubin et al., 2007). Adopting a more individually tailored approach could possibly increase the efficacy (Frick, 2016; Rubin et al., 2007), yet in order to do so, it is important to consider different types of antisocial behavior (Ogilvie et al., 2011; Popovici et al., 2014; Pulkkinen, 2001) and their facilitating factors, such as distortions in cognitive thinking (Barriga et al., 2000; Chabrol et al., 2011; Gannon et al., 2009; Wallinius et al., 2011) and possibly related, deficits in cognitive control (Aharoni et al., 2013; Steele et al., 2017). More specifically, it has been previously suggested to distinguish between legal (e.g., any registered criminal offense), clinical (e.g., antisocial personality), and aggressive (e.g., any act of violence) behavior, as these may show unique relationships with their facilitators (Ogilvie et al., 2011; Popovici et al., 2014; Pulkkinen, 2001). Aggression can be further subdivided into proactive (premediated, instrumental, and offensive) and reactive (defensive, in reaction to an anticipated anger-associated threat) aggression (Dodge et al., 1990), as these are thought to have different underlying pathways including different correlates with social information processing (SIP) steps (Castro, 2004).

Biases or alterations in social information processing might underlie antisocial behavior. The SIP-theory posits that all social behavior relies on six sequential cognitive steps, namely encoding of cues (1); interpreting these cues, including attribution (2); clarifying and selecting a goal (3); generating possible responses (4); evaluating and selecting the responses (5); and enacting the selected response (6) (Crick & Dodge, 1994). Disruptions can occur in any of these steps, such as the hostile attribution bias (encoding and interpreting information in a hostile manner), which has been previously associated with reactive aggression (Castro, 2004; Lobbestael et al., 2013). Biased information processing arises through inaccurate social cognitions, specifically those that assist self-justifying acts of antisocial behavior (i.e., self-serving cognitive distortions) (Barriga et al., 2000).

Barriga and Gibbs (1996) identified four types of self-serving cognitive distortions, classified as primary (i.e., self-centeredness) and secondary (i.e., blaming others, assuming the worst, and minimizing/mislabeling) distortions. Self-centeredness can be defined as the focus on one's own rights, needs, opinions, and expectations to an extent that the legitimate views of others are rarely or never considered. Blaming others means misattributing one's blame to an external locus of control. Assuming the worst is the consideration of the worst-case scenario as inevitable, the assumption that one's behavior is beyond improvement, and the attribution of hostile intentions to others. And last, minimizing/mislabeling is depicting antisocial behavior as harmless, acceptable, or necessary and/or referring to others in a dehumanizing and belittling way).

Due to the heterogeneous nature of antisocial behavior, it could be expected that distinct cognitive distortions are uniquely related to distinct antisocial behaviors (Chabrol et al., 2011; Smeets et al., 2017). This is exemplified in prior studies on aggression in children and adolescents, where reactive aggression related to blaming others, whilst proactive aggression related to self-centeredness (Koolen et al., 2012; Oostermeijer et al., 2017). This has not been studied in other types of antisocial behavior, although related research suggests possible distinct correlations between criminal offenses and assuming the worst (Van Rest et al., 2014), and between antisocial personality behavior and assuming the worst and minimizing/mislabeling (Hessels et al., 2016; Matthys & Lochman, 2008)**.** In sum, it is relevant to address different measures of antisocial behavior and the possible unique associations with cognitive distortions.

In addition to distortions in cognitive patterns, antisocial behavior has also been repeatedly linked to deficits in cognitive control (Aharoni et al., 2013; Chamberlain et al., 2016; Ogilvie et al., 2011; Zeier et al., 2012). Cognitive control (or executive functioning) is a higher-order neuropsychological construct critical for goal- and future-oriented behavior, including the ability to anticipate the (negative) consequences of antisocial behavior. A common pervasive pattern related to antisocial behavior is the apparent inability to learn from prior experiences, indicating possible deficits in the monitoring and adjusting of one's behavior following errors (Hall et al., 2016). Indeed, failure in the detection and reaction to errors (i.e., impaired error processing) has been previously found in populations displaying antisocial behavior including (young) adults facing various problems such as drug use, antisocial behavior, and psychological problems (Aharoni et al., 2013; Orr & Hester, 2012; Zijlmans et al., 2019).

Error processing, as an index of cognitive control, could serve as a potential moderator in the association between cognitive distortions and antisocial behavior. That is, intact or strong error processing could decrease the possibility of antisocial outcomes through the exertion of voluntary self-regulation and effortful control (Gardner et al., 2008; Loeber et al., 2007; Nigg et al., 2007), decreasing the possible negative effects of self-serving cognitive distortions. Conversely, impaired error processing could increase the likelihood of antisocial outcomes through impaired ability to regulate and adapt one's behavior (Caprara et al., 2007; Siever, 2008), amplifying any possible negative effects of self-serving cognitive distortions. This is further supported by the assumption that cognitive control as higher-order ability affects other cognitive functions, including social information processing. Indeed, previous research demonstrated a link between impaired cognitive control (indexed as working memory, inhibition, and performance on the Flanker task) and biased information processing (Van Nieuwenhuijzen et al., 2017; Van Nieuwenhuijzen & Vriens, 2012). In other words, it is possible that individual differences in cognitive control (indexed as error processing) yield different outcomes in the presence of self-serving cognitive distortions.

To our knowledge, the current study is the first study to examine the moderating effect of error processing in the relationship between self-serving cognitive distortions and different types of antisocial behaviors. Error processing is measured with the error-related negativity (ERN), an event-related potential (ERP) during electroencephalography generated in the anterior cingulate cortex (ACC) (Edwards et al., 2012; Orr & Hester, 2012). Previous studies suggest a moderating effect of other measures of cognitive control such as inhibitory control and attention shifting in the relationship between behavioral inhibition and anxiety symptoms in children (White et al., 2011a) and in the relationship between childhood-onset anger and antisocial personality features in adulthood (Hawes et al., 2016). That being said, it is important to note that these studies only used behavioral measures of cognitive control (e.g. reaction time on inhibition tasks) and did not focus on young adults.

Research on the relationship between self-serving cognitive distortions, error processing, and antisocial behavior can aid in the understanding and prevention of antisocial outcome. For example, cognitive-behavioral interventions could target specific self-serving cognitive distortions to treat the related antisocial behaviors rather than addressing all distortions as interrelated constructs. In addition, previous research suggests that various measures of cognitive control may be improved via cognitive interventions including meditation (Larson et al., 2013; Wiers et al., 2013) and through physical activity (Gomez-Pinilla & Hillman, 2013; Verburgh et al., 2014), which increases neural efficiency in the prefrontal cortex (Erickson et al., 2015; Voss et al., 2011). As such, it may be possible to improve error processing in multi-problem young adults, which in turn, may be related to decreased antisocial outcomes despite the presence of self-serving cognitive distortions.

Although self-serving cognitive distortions and error processing both relate to antisocial behavior, it remains unclear whether specific self-serving cognitive distortions relate differently to specific antisocial behaviors and whether error processing (indexed as ERN) moderates this relationship. The current study aims to fill this gap in a sample of young adult men displaying a range of problems, including externalizing behaviors, frequent substance use, and a history of delinquency (Luijks et al., 2017; van Duin et al., 2017, 2018; Zijlmans et al., 2018, 2019, 2020). First, the relationship between self-serving cognitive distortions (i.e., self-centeredness, blaming others, minimizing/mislabeling, and assuming the worst) and different types of antisocial behavior (i.e., antisocial personality behavior, reactive aggression, proactive aggression, and criminal offenses) will be examined. Previous studies have identified IQ (Stevens et al., 2003) and substance abuse (Hussong et al., 2004) as possible covariates in the prediction of antisocial behavior and these will thus be included. Second, the possible moderating effect of error processing will be explored for all relationships between self-serving cognitive distortions and antisocial behavior. It is hypothesized that reactive aggression is associated with blaming others, and proactive aggression with self-centeredness (Koolen et al., 2012; Oostermeijer et al., 2017). It is further expected that antisocial personality behavior is related to assuming the worst and minimizing/mislabeling (Hessels et al., 2016; Matthys & Lochman, 2008)**.** Lastly, we expect criminal offenses to be associated with assuming the worst (Van Rest et al., 2014). Based on the (scarce) relevant literature on behavioral measures of cognitive control, we expect a moderating effect of ERN during error processing (Hawes et al., 2016; White et al., 2011a).

Methods and materials

Participants

Participants were 696 multi-problem young adults recruited in Rotterdam, the Netherlands (Luijks et al., 2017; Van der Sluys et al., 2020; van Duin et al., 2017, 2018; Zijlmans et al., 2018, 2019, 2020, 2021), of which the first 127 eligible participants were selected for the electroencephalography (EEG) protocol. They were recruited from two sites: 177 participants at a municipal agency (Dutch: *Jongerenloket)* and 519 participants at the day treatment program at *De Nieuwe Kans* (DNK; translated as “New Opportunities”). Recruited participants from both sites were comparable, e.g. all were men, ranging in age from 18 to 27 (mean age at baseline 22.0, SD 2.4, for more demographics, see Table 1). At the first site, the municipal agency, young adults between the ages 18 and 27 can apply for social welfare and they can be referred to various interventions, such as the treatment at DNK. Participants at the municipal agency were eligible for study participation if they were men and classified as multi-problem as measured by the Dutch Self-Sufficiency Matrix (Fassaert et al., 2014; Luijks et al., 2017). The Self-Sufficiency Matrix assesses self-sufficiency on various life domains such as mental health and physical health, and the scores range from 1 (acute problems) to 5 (completely self-sufficient). A participant was classified as multi-problem based on the following criteria: a maximum score of 3 on at least one of the following domains: Justice, Social Network, Addiction, and Mental Health; a score of 1 or 2 on the Income and Daytime-activities domains; and a score of 3 or higher on the Physical Health domain (Luijks et al., 2017). At the second site, DNK, participants receive a multimodal day treatment that is specifically designed to treat multi-problem young adult men (18 - 27) with a variety of problems, including antisocial behavior, drug use, psychological problems, and financial problems (van Duin et al., 2017). DNK applies a combination of cognitive behavioral techniques and practical support to treat behavioral problems and antisocial behavior, particularly with the goal to reintegrate participants back into the society through education and employment.

For the first research question, which examined the relationship between self-serving cognitive distortions and antisocial behaviors, we performed analyses on the total sample (N = 696). For the second supplementary question on the possible moderating effect of cognitive control, we performed supplemental analyses on a subset of participants who completed the EEG protocol (n = 127). A more detailed account of data reduction is provided in the procedure section.

All procedures in the present study were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments and comparable ethical standards. The study was approved by the Medical Ethical Committee of the VU University Medical Center (registration number 2013.422 - NL46906.029.13), and all participants provided written informed consent after they received an explanation from a trained researcher. Regarding the EEG protocol, the first 127 candidates that provided informed consent to participate in this part of the study were included. Participants received a reimbursement of 20 euros for completing the questionnaires and an additional 30 euros for participating in the EEG protocol.

Measurements

*Predictors***.** The Dutch translation of the How I Think Questionnaire (HIT; (Fassaert et al., 2014)) was used to measure self-serving cognitive distortions at baseline. This 54-item self-report questionnaire is designed to measure four categories of self-serving cognitive distortions: self-centeredness, blaming others, minimizing/mislabelling, and assuming the worst (Gini & Pozzoli, 2013). Items were rated with a six-point scale ranging from strongly disagree (1) to strongly agree (6) and summated to create a total for each category. A higher score indicated greater self-serving cognitive distortions. The internal reliability of this measure is noted to be high, with Cronbach's alphas that ranged from .66 and .92 for the four subscales and an overall internal consistency that ranged from .90 to .94 (Nas et al., 2008).

Previous studies have identified IQ (Stevens et al., 2003) and substance abuse (Hussong et al., 2004) as possible covariates in the prediction of antisocial behavior. An IQ-score was measured with the digit symbol coding, information, block design, and arithmetic subscales of the Wechsler Adult Intelligence Scale third version (WAIS-III SF; (Blyler et al., 2000)). Subtest reliability of the used WAIS-III-subscales ranges from .84 to .91 with average IQ reliability ranging from .94 to .98 (Silva, 2008). Years of regular (i.e., weekly) cannabis use and years of regular (i.e., weekly) alcohol use were assessed with the Measurements in the Addictions for Triage and Evaluation Questionnaire (MATE) (Schippers et al., 2010). The MATE has adequate validity and good inter-rater reliability ranging between .75 and .92 (Schippers et al., 2010). IQ and substance use were measured at baseline at the municipal agency or at DNK.

*Outcomes***.** Four different constructs of antisocial behavior were assessed: antisocial personality behavior, proactive aggression, reactive aggression, and number of criminal offenses.

Antisocial personality behavior at baseline was assessed with the percentile score on the antisocial personality scale of the Adult Self Report (ASR) (Barriga & Gibbs, 1996). The ASR is a 126-item self-report questionnaire for adults, designed to assess various categories of psychopathology, which is consistent with the diagnostic categories of the Diagnostic and Statistical Manual of Mental Disorders 4th edition (DSM-IV: (*Diagnostic and Statistical Manual of Mental Disorders.*, 2000)). All items can be answered with never (0), sometimes (1), or often (2). Internal consistency and test-retest stability of the scales are good (Achenbach & Rescorla, 2003).

Baseline reactive and proactive aggression were examined by the Dutch Reactive- Proactive Aggression Questionnaire (RPQ), which is a self-report questionnaire that contains 23 items to measure these two types of aggression (Raine et al., 2006). Items were rated with never (0), sometimes (1), or often (2) and summated to create subscales. The test-retest reliability and internal consistency of the RPQ ranged from good to excellent, with Cronbach's alpha's reported of .83 and higher (Cima et al., 2013; Raine et al., 2006).

Criminal offenses refer to the number of convicted crimes in a specific time period, identified as from birth to the point of the database query (January 3rd 2018; hereafter termed as 'follow-up'). To measure this, documentation was requested on all criminal offenses recorded by the Research and Policy database Judicial Documentation (OBJD) by the Research Documentation Center (WODC) of the Ministry of Security and Justice in the Netherlands from birth to follow-up. There were 4 participants whose offense documentation were missing, as they did not give permission to request their documentation. Therefore, they were excluded from the analyses, resulting in N = 692 participants with information on criminal offenses. To control for the time at risk of offending, age at follow-up was included in the analysis.

*Moderator***.** Error processing was measured with the response-locked ERN during an error processing task (Eriksen-Flanker). ERN measures were acquired by recording brain activity with a Biosemi ActiveTwo System amplifier to measure the EEG during an Eriksen-Flanker task previously used by Zijlmans et al (Zijlmans et al., 2019). Participants were asked to respond to letter strings (HHHHH, SSSSS, HHSHH, SSHSS) by pressing a letter on the QWERTY-keyboard corresponding to the middle letter of the string with their left (S) or right (H) index finger. Each string was presented for 52 ms with a maximum response time of 648 ms. The trial was preceded by a fixation cross for 150 ms and ended with a feedback symbol for 500 ms (+, - or !, respectively correct, incorrect, or too late). The stimulus interval was set at 100 ms, making the total trial duration 1450 ms. A total of 400 trials were presented per participant, which was divided into 5 blocks. Each block ended with a break that lasted as long as the participant needed. In total, 33 silver chloride (Ag/AgCl) electrodes (32-cap + 1 external electrode at FCz) were placed on the scalp according to the 10-20 International System, with two reference electrodes on the left and right mastoids. Signals were digitized with a sampling rate of 512 Hz and 24-bit analogue-to-digital conversion. A low cutoff of 0.15 Hz and a high cutoff of 30 Hz (24 dB/octave slope) were used for offline filtering. Ocular artifacts were controlled for by assessing the vertical and horizontal electro-oculogram. Additional artifact rejection (+/-100 µV) was performed automatically. The -100 – 0 ms pre-response period served as baseline. The ERN was defined as the response-locked difference in mean amplitude between correct and incorrect responses in a 25-100 ms time window on the FCz electrode. Notably, since the

ERN difference wave is a negative deflection, a more negative mean value corresponds to a higher ERN (i.e., increased error processing).

Procedure

All variables were measured at baseline, with the exception of the data on offenses, which was requested by a database query on January 3th 2018 (median follow-up time = 30 months, range = 13-47). Baseline data was collected by trained researchers within the first two weeks of entry at DNK or at the municipal agency with questionnaires in the form of a structured interview. The baseline questionnaires were administered in a maximum of two sessions, which were independent of that of the EEG measurements. EEG measurements were assessed in a separate session at the Erasmus Behavioral Lab at the Erasmus University Rotterdam in a sound-attenuated room with dimmed lights. Participants were seated in a comfortable chair. After explanation of the task by a trained researcher, participants started with a practice trial followed by the experiment.

Statistical analyses

To account for missing data on all variables excluding outcomes, we imputed to 40 complete sets (White et al., 2011b) using Stata Statistical Software, version 14 (StataCorp). The imputation was done before exclusion, as the excluded participants only needed to be excluded for specific analyses (e.g. the participants with missing documentation on offenses could still be used in the other linear regression analyses). First, four hierarchical linear regression analyses were performed on the total sample (N = 696) to address the relationship between the four self-serving cognitive distortions (self-centeredness, minimizing/mislabeling, assuming the worst, blaming others) and the four types of antisocial behavior (antisocial personality behavior, reactive and proactive aggression, and number of criminal offenses). Thus, each analysis contained the four predictors (the self-serving cognitive distortions) and one antisocial outcome measure. One participant was excluded from the analyses with reactive and proactive aggression due to missing information on the RPQ. From the analysis with offenses, four participants were excluded because documentation on offenses was missing. Participants were excluded after the imputation process. The final sample for the reactive and proactive analyses consisted of 695 participants. The final sample for the offending analysis consisted of 692 participants.

Second, 16 supplementary hierarchical multiple regression analyses with centered interaction terms were performed to examine the possible moderating effect of error processing (i.e., ERN during error processing) on all possible associations. Each moderator analysis contained one cognitive distortion, the ERN moderator, and one antisocial outcome measure. These analyses were performed on a smaller subsample of participants in the EEG protocols (n = 127). Documentation on offenses was missing for one participant, resulting in a final sample of 126 participants for this analysis. As Bonferroni correction assumes independence of the tests and is shown to be overly conservative when parameters overlap (Cribbie, 2000, 2007) and due to the explorative nature of these analyses, the uncorrected results are presented.

IQ, years of regular alcohol use, and years of regular cannabis use were added as covariates in all regression analyses. Additionally, age at follow-up was included as a covariate in the analyses with offenses as the outcome variable. Cohen's rule of thumb was used to estimate effect sizes (adjusted R^2) with .001 being small, .09 being moderate, and .25 being large (Cohen, 1988). An alpha of .05 was used. All analyses were performed using Stata Statistical Software, version 14 (StataCorp).

Results

Descriptive statistics are shown in Table 1.

Table 1 Descriptive statistics

Variable	N = 696		N = 127	
	M (range)	*SD*	*M* (range)	*SD*
Age	22.05 (18-27)	2.44	21.97 (18-27)	2.39
IQ	80.84 (46-130)	10.84	82.05 (59-107)	10.40
Years of regular cannabis use	3.16 (0-15)	3.69	4.18 (0-14)	3.85
Years of regular alcohol use	1.99 (0-17)	3.20	2.19 (0-13)	3.53
Age at follow-up[a]	25.02 (19-31)	2.58	24.89 (19-29)	2.49
HIT Self-Centered	22.33 (2-48)	7.12	23.24 (6-39)	6.70
HIT Blaming Others	22.79 (1-50)	7.59	23.81 (6-44)	7.74
HIT Minimizing/Mislabeling	20.91 (2-45)	6.69	21.41 (6-37)	6.45
HIT Assuming the Worst	25.86 (3-54)	7.78	26.55 (9-53)	7.55
RPQ reactive aggression	10.83 (0-22) [c]	4.75	11.27 (0-22)	4.64
RPQ proactive aggression	4.93 (0-22) [c]	4.43	5.28 (0-19)	4.27
ASR antisocial personality behavior	74.49 (50-99)	18.12	76.18 (50-99)	17.77
Number of offenses	8.21 (0-54) [d]	8.18	7.22 (0-37) [e]	6.94
ERN during error processing [b]	n/a	n/a	-4.85 (-20-14)	5.36

Note. Due to non-imputed outcome measures, N can vary between outcome variables. M and SD represent mean and standard deviation, respectively. HIT = How I Think questionnaire; IQ = intelligence quotient; RPQ = Reactive Proactive Questionnaire; ASR = Adult Self Report; ERN = error-related negativity; DSM = Diagnostic and Statistical Manual of mental Disorders.
[a] only included in the regressions with number of offenses.
[b] Only measured in smaller subsample of N = 127; lower score indicating less adequate error processing
[c] N = 695
[d] N = 692
[e] N = 126

Associations between self-serving cognitive distortions and antisocial behaviors

For the first aim, four multiple hierarchical linear regressions were performed to assess the association between all self-serving cognitive distortions and the four antisocial behaviors in the total sample. Results of the first linear regression with antisocial personality behavior are shown in Table 2. The model including only the covariates was significant (F (3, 637.3) = 18.99, $p < .001$), with a small effect size ($R^2 = .081$). Significant positive unique associations were uncovered between regular cannabis use and regular alcohol use. When controlling for covariates, the model including all self-serving cognitive distortions was also significant (F (7, 493.6) = 24.39, $p < .001$) with a large effect size ($R^2 = .282$), $\Delta R^2 = .142$ ($p < .001$). In addition, a positive significant association was found between self-centeredness and antisocial personality behavior. All covariates (IQ, regular alcohol use and regular cannabis use) also showed a positive association with antisocial personality behavior.

Table 2 Hierarchical linear regression with antisocial personality behavior as outcome

	B	*SE (B)*	*t*	*p*	95% CI B Lower	Upper
Step 1						
constant	59.83	5.62	10.764	.000	48.76	70.89
IQ	0.12	0.06	1.81	.072	-0.01	0.26
Years of regular cannabis use	1.05	0.20	5.21	.000***	0.65	1.44
Years of regular alcohol use	0.62	0.23	2.71	.007**	0.17	1.07
Step 2						
constant	25.61	6.00	4.27	.000	13.79	37.44
IQ	0.20	0.06	3.13	.002**	0.07	0.32
Years of regular cannabis use	0.60	0.19	3.09	.002**	0.21	0.99
Years of regular alcohol use	0.46	0.22	2.07	.039*	0.02	0.90
HIT Self-Centered	0.57	0.17	3.23	.002**	0.22	0.92
HIT Blaming Others	0.17	0.17	0.96	.339	-0.18	0.52
HIT Minimizing/Mislabeling	0.14	0.21	0.67	.504	-0.28	0.57
HIT Assuming the Worst	0.38	0.19	1.91	.059	-0.01	0.77

Note. N = 692. HIT = How I Think questionnaire; IQ = intelligence quotient.
* p < .05. ** p < .01. *** p < .001

Results of the second linear regression with reactive aggression are shown in Table 3. The model including only the covariates was significant (*F* (3, 638.5) = 15.95, $p < .001$) with a small effect size (R^2 = .064). One significant unique positive association was found with regular cannabis use. The model remained significant after adding all self-serving cognitive distortions (*F* (7, 526.6) = 18.57, $p < .001$) with a medium-large effect size (R^2 = .216), ΔR^2 = .152 ($p < .001$). Self-centeredness and regular cannabis use showed a significant positive association with reactive aggression.

Table 3 Hierarchical linear regression with reactive aggression as outcome

	B	*SE (B)*	*t*	*p*	95% CI B Lower	Upper
Step 1						
Constant	8.97	1.47	6.10	.000	6.08	11.87
IQ	0.00	0.01	0.53	.595	-0.02	0.04
Years of regular cannabis use	0.31	0.05	5.96	.000***	0.21	0.42
Years of regular alcohol use	0.03	0.06	0.61	.545	-0.08	0.15
Step 2						
constant	0.99	1.64	0.61	.545	-2.24	4.23
IQ	0.02	0.01	1.64	.103	-0.00	0.06
Years of regular cannabis use	0.21	0.05	4.06	.000***	0.11	0.31
Years of regular alcohol use	0.00	0.06	0.05	.958	-0.11	0.12
HIT Self-Centered	0.09	0.04	2.08	.039*	-0.00	0.19
HIT Blaming Others	0.05	0.04	1.24	.217	-0.03	0.15
HIT Minimizing/mislabeling	0.06	0.05	1.26	.211	-0.03	0.17
HIT Assuming the Worst	0.07	0.04	1.45	.150	-0.02	0.17

Note. N = 695. HIT = How I Think questionnaire; IQ = intelligence quotient. Adjusted R^2 for step 1 = .064, adjusted R^2 for step 2 = .216, ΔR^2 = .152 ($p < .001$).
* $p < .05$. *** $p < .001$

Results of the third linear regression with proactive aggression as the outcome are shown in Table 4. The first model with the covariates was significant (F (3, 627.6) = 15.60, p < .001) with a small effect size (R^2 = .068). A significant positive association was discovered for regular cannabis use. The second model containing the covariates and self-serving cognitive distortions was significant (F (7, 542.8) = 16.81, p < .001) with a medium effect size (R^2 = .194), ΔR^2 = .126 (p < .001). Significant positive associations with proactive aggression were found for self-centeredness and regular cannabis use.

Table 4 Hierarchical linear regression with proactive aggression as outcome

					95% CI B	
	B	*SE (B)*	*t*	*p*	Lower	Upper
Step 1						
constant	5.18	1.36	3.80	.000	2.50	7.87
IQ	-0.01	0.01	-0.97	.331	-0.04	0.01
Years of regular cannabis use	0.27	0.05	5.50	.000***	0.17	0.37
Years of regular alcohol use	0.09	0.05	1.65	.099	-0.01	0.21
Step 2						
constant	-1.48	1.56	-0.95	.343	-4.56	1.59
IQ	-0.00	0.01	-0.05	.961	-0.03	0.03
Years of regular cannabis use	0.19	0.04	3.80	.000***	0.09	0.28
Years of regular alcohol use	0.06	0.05	1.10	.271	-0.05	0.17
HIT Self-Centered	0.09	0.04	2.16	.032*	0.00	0.18
HIT Blaming Others	0.04	0.04	0.97	.334	-0.04	0.12
HIT Minimizing/Mislabeling	0.08	0.05	1.66	.099	-0.01	0.18
HIT Assuming the Worst	0.03	0.04	0.78	.439	-0.05	0.12

Note. N = 695. HIT = How I Think questionnaire; IQ = intelligence quotient.
* p < .05. *** p < .001

Table 5 Hierarchical linear regression with number of offenses as outcome

					95% CI B	
	B	*SE (B)*	*t*	*p*	Lower	Upper
Step 1						
constant	7.04	4.00	1.76	.007**	-0.81	14.90
IQ	-0.09	0.03	-3.10	.002**	-0.15	-0.03
Years of regular cannabis use	0.08	0.09	0.88	.377	-0.10	0.26
Years of regular alcohol use	0.25	0.10	2.36	.018**	0.04	0.47
Age at follow-up	0.32	0.12	2.56	.011**	0.07	0.57
Step 2						
constant	5.16	4.74	1.09	.276	-4.15	14.49
IQ	-0.09	0.03	-2.98	.003**	-0.5	-0.03
Years of regular cannabis use	0.06	0.09	0.70	.486	-0.12	0.26
Years of regular alcohol use	0.23	0.11	2.10	.036*	0.01	0.45
Age at follow-up	0.35	0.13	2.65	.008**	0.09	0.61
HIT Self-Centered	0.03	0.08	0.44	.662	-0.13	0.21
HIT Minimizing/Mislabeling	0.02	0.11	0.25	.806	-0.19	0.24
HIT Blaming Others	-0.07	0.08	-0.88	.382	-0.23	0.08
HIT Assuming the Worst	0.05	0.09	0.60	.552	-0.12	0.23

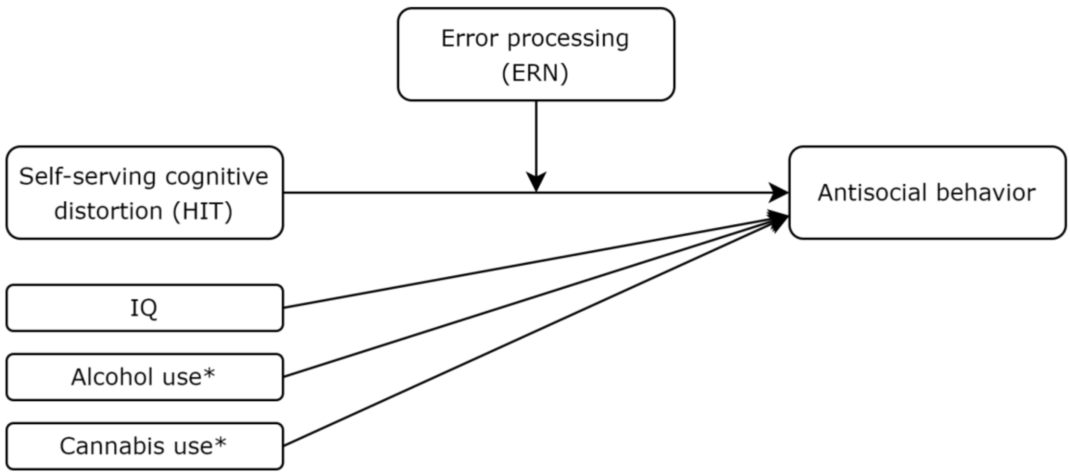
Note. N = 692. HIT = How I Think questionnaire; IQ = intelligence quotient.
* p < .05. ** p < .02

Results of the fourth regression with offenses are shown in Table 5. The model with only the covariates (i.e., IQ, regular alcohol use and cannabis use, age at follow-up) was significant (F (4, 671.3) = 7.83, p < .001), with a small effect size (R^2 = .041). A significant negative relationship was found with IQ, and significant positive associations with regular alcohol use and age at follow-up. After adding the self-serving cognitive distortions, the model remained significant (F (8, 590.2) = 3.33, p = .001), but with a small effect size (R^2 = .042), ΔR^2 = .001 (p < .001). None of the individual self-serving cognitive distortions showed a significant unique association with criminal offenses, but IQ (negative), regular alcohol use (positive), and age at follow-up (positive) remained significant.

Moderating effect of error processing

For the second aim, the possible moderating effect of error processing as indexed by ERN was examined for all possible associations (i.e., the four self-serving cognitive distortions and the four antisocial measures). IQ, regular cannabis use, and regular alcohol use were included as covariates in all analyses. Age at follow-up was additionally included in the analyses concerning total offenses. See Figure 1 for a schematic visualization of the general model with cognitive control. Due to dependency between the tests, only the uncorrected results will be shown.

Figure 1 Schematic visualization of the general model testing the association between self-serving cognitive distortions and antisocial behavior with cognitive control as moderator



Note. HIT = How I Think questionnaire; IQ = intelligence quotient; ERN = error-related negativity
* regular (i.e., weekly) alcohol and cannabis use in years

No significant moderating effects were found in any of the analyses. However, significant positive main effects with all self-serving cognitive distortions were uncovered in all models predicting antisocial personality behavior: self-centeredness (B = 0.87, p < .02), blaming others (B = 0.83, p < .02), minimizing/mislabeling (B = 1.01, p < .02), and assuming the worst (B = 0.95, p < .02). Likewise, we found significant main effects in all models predicting reactive aggression: self-centeredness (B = .20, p < .02), regular cannabis use in the self-centered model (B = 0.26, p < .05), blaming others (B = 0.20, p < .02), regular cannabis use in the blaming others model (B = 0.26, p < .05), minimizing/mislabelling (B = 0.29, p < .02), regular cannabis use in the minimizing/mislabeling model (B = 0.27, p < .05), assuming the worst (B = 0.26, p = .02), and regular cannabis use in the assuming the worst model (B = 0.28, p < .02).

Furthermore, in all models predicting reactive aggression, regular cannabis use also showed a significant positive association: regular cannabis use in the self-centered model (B = 0.26, $p < .05$), regular cannabis use in the blaming others model (B = 0.26, $p < .05$), regular cannabis use in the minimizing/mislabeling model (B = 0.27, $p < .05$), and regular cannabis use in the assuming the worst model (B = 0.28, $p < .02$).

Lastly, in the models including proactive aggression and total offenses (including age at follow-up), no significant main effects were uncovered.

Discussion

Prior literature has linked self-serving cognitive distortions to antisocial behavior in general (Barriga et al., 2000; Chabrol et al., 2011; Wallinius et al., 2011), yet very few studies examined the specificity of this association between various distortions and different types of antisocial behavior. The current study attempted to fill this gap by studying the unique association between four self-serving cognitive distortions (i.e., self-centeredness, blaming others, minimizing/mislabeling, and assuming the worst) and four variations of antisocial behavior (i.e., antisocial personality behavior, reactive aggression, proactive aggression, and criminal offenses. Additionally, we examined for the first time, the possible moderating effect of cognitive control indexed by the error-related negativity (ERN) during error processing on these associations. First, only the primary cognitive distortion self-centeredness was related to antisocial personality behavior and both reactive and proactive aggression. No other associations were uncovered. Second, results of the explorative aim showed that our measure of cognitive control (i.e., ERN during error processing) did not moderate any of the associations between self-serving cognitive distortions and antisocial behavior.

Our hypotheses were partly confirmed, as we expected an association between self-centeredness and proactive aggression (Koolen et al., 2012; Oostermeijer et al., 2017), but not with reactive aggression and antisocial personality behavior. None of the other hypotheses were confirmed (i.e., we found no association between blaming others and proactive aggression, assuming the worst and criminal offenses and antisocial personality behavior (Hessels et al., 2016; Matthys & Lochman, 2008; Van Rest et al., 2014), and between minimizing/mislabeling and antisocial personality behavior (Hessels et al., 2016; Matthys & Lochman, 2008)). The current results indicate that self-centeredness (i.e., the focus on one's viewpoint to the extent that it ignores others' viewpoints) is related to various measures of antisocial behavior or related personality behavior, namely antisocial personality behavior, reactive aggression, and proactive aggression. This is partly in line with previous studies on aggression in healthy children (Koolen et al., 2012) and adolescents with behavioral problems (Oostermeijer et al., 2017), where self-centeredness was related to proactive but not reactive aggression. It may be possible that self-centeredness becomes more prominent in young adulthood compared to adolescence or childhood in multi-problem young adults, possibly through repeated exposure, which may explain the difference between existing literature on children and adolescents and our current study on young adults. Both the social learning theory (aggressive behavior can be learned by observing others' behavior) and the social information processing theory (aggressive behavior is the result of biased social processing) (Liu et al., 2013) may support this hypothesis. As such, it may be that our sample of multi-problem young adults has learned to perceive not only the calculated proactive aggression, but also the impulsive reactive aggression as an effective tool to reach egocentric goals (Koolen et al., 2012). The results of the current study are also partly in line with a previous study in adolescents, where self-centeredness and assuming the worst were both significant predictors of multiple potential problem areas including self-reported aggressive behavior and delinquency (Vrucinic & Vasijevic, 2021). It is possible that the distortion assuming the worst is only an important predictor during adolescence, but not during young adulthood.

Unexpectedly, we did not uncover any other associations between the distortions and current measures of antisocial behavior. This is in line with the classification of primary (self-centeredness) and secondary (blaming others, minimizing/mislabeling, and assuming the worst) distortions (Gibbs, 1993). The primary distortions concern the rationalizations related to the egocentric motivation of antisocial behavior and the sense of being above the law, whereas the secondary distortions serve to support the primary distortion by preventing damage to the self by neutralizing empathy and guilt. The lack of an association with the secondary distortions may indicate a low need to neutralize or complete lack of feelings such as guilt and remorse. Antisocial personality behavior, which is characterized by lack of guilt and remorse, is relatively common among incarcerated offenders (Black et al., 2010) and in our current sample. Based on the Adult Self Report, 41% of the multi-problem young adults would be (borderline) clinical. This relatively high prevalence may indicate that these young adults do not experience any emotional distress due to lack of guilt or remorse, and thus do not feel the need to neutralize such feelings.

No significant associations with number of offenses were uncovered, in contrast with our expectations. This is in line with a study where previous convictions in adult offenders were not related to individual self-serving cognitive distortions (Wallinius et al., 2011), but not in line with two studies in which the total score on self-serving cognitive distortions was related to institutional misconduct in incarcerated adolescents (Barriga et al., 2000) and to committing aggravated assault in youth offenders (Tisak & Goldstein, 2021). Definite conclusions are hampered by the scarcity of literature on this topic, but these results suggest that individual cognitive distortions may be related to general (unregistered) antisocial behaviors such as aggression, behavior related to antisocial personality behavior, and self-reported convictions, but not to (registered) acts of antisocial behavior such as number of registered offenses. However, this does not explain why offenders show more self-serving cognitive distortions compared to non-offenders (Lardén et al., 2006; Wallinius et al., 2011).

Additionally, we found the expected associations between antisocial behavior and most of our covariates (i.e., regular cannabis and regular alcohol use, and IQ), in line with previous studies on cannabis and alcohol (mis)use (Boden et al., 2013; Miller et al., 2020; Parmar & Kaloiya, 2018) and IQ (Tegeng & Abadi, 2018). Surprisingly, higher IQ was also related to more antisocial personality behavior in our sample of multi-problem young adults. This is not supported by a previous meta-analysis where lower IQ was related to higher scores on psychopathic traits (Sánchez de Ribera et al., 2019). Although speculative, some participants may have over-reported their antisocial personality behavior, possibly using these symptoms as an excuse for their behavior (Maruna & Mann, 2006). This requires a level of deception, which may only be present in participants with a higher IQ. Furthermore, although most models with only the covariates were significant, the inclusion of the distortions resulted in significantly larger effect sizes, stressing the importance of including self-serving cognitive distortions in the prediction of antisocial behavior, which is supported by previous studies (Andrews & Bonta, 2010; Barriga et al., 2000; Chabrol et al., 2011; Wallinius et al., 2011).

Last, we did not find the expected significant moderating effect, suggesting cognitive control as indexed by ERN during error processing does not serve as a protective or risk factor against antisocial outcomes in the presence of cognitive distortions. A possible explanation may be that ERN activity occurs too early in time. Self-serving cognitive distortions can be interpreted as biased processing of social information (Crick & Dodge, 1994), resulting in unwanted and antisocial behaviors (Barriga et al., 2000). ERN (i.e., automatic error processing) is a very early process occurring milliseconds after a response (Bernstein et al., 1995). Social information processing on the other hand, can be seen as a late process, which occurs more consciously (Crick & Dodge, 1994). It is therefore possible that the current index of cognitive control occurs too early to influence biases in social information processing (i.e., self-serving cognitive distortions). Although we could not find a moderating effect of error processing, the current results can be seen as a first step in exploring the possible role of cognitive control in variations in the severity of antisocial outcomes related to cognitive distortions.

The present study must be interpreted in light of some limitations. For example, substance use prior to the EEG session was only assessed with self-report and was not tested objectively with a breathalyzer or urine screen tests. Therefore, it is possible that the EEG results may have been distorted due to unnoticed substance use. However, all participants reported refraining from substance use prior to the EEG session. Furthermore, as the current study relies on previously collected data, no a priori sample size calculation could be performed for the current moderator analyses. For the previously collected data, an a priori sample size calculation was performed for a linear regression model without interaction terms (Zijlmans et al., 2018, 2019, 2021). A post-hoc calculation for the moderation analyses with the expectation of a small to medium effect size f2 (0.09: (Aguinis et al., 2005)), for a power of 0.80 and an alpha of .05, resulted in a required sample size of N = 175. As the additional moderation analyses were performed on a smaller subsample, these analyses may have lacked power. However, the main analysis had sufficient power.

In conclusion, we found the primary self-serving cognitive distortion (i.e., self-centeredness), but none of the secondary (i.e., blaming others, assuming the worst, and minimizing/mislabelling) to be related to different types of antisocial behaviors (i.e., antisocial personality behavior, reactive aggression, proactive aggression) in multi-problem young adults. These findings address the need to differentiate between primary and secondary self-serving cognitive distortions rather than focusing on one general antisocial mindset. Indeed, existing interventions addressing cognitive distortions are mostly cognitive behavioral-based interventions such as EQUIP (Gibbs et al., 1995), in which self-serving cognitive distortions are addressed as interrelated constructs. The results of the current study together with the findings of previous studies demonstrate that these distortions, specifically self-centeredness, should possibly be treated separately in treatment programs, for example by including psychotherapy (commonly used to treat narcissistic personality disorder) (Campbell & Miller, 2012). In addition, ERN during error processing did not moderate this relationship, suggesting that individual differences in this measure of cognitive control do not yield different antisocial outcomes in the presence of self-serving cognitive distortions. Overall, the current results indicate the need for addressing specific cognitive biases related to specific antisocial behaviors rather than treating them as one general antisocial bias, however not through interventions addressing ERN during error processing.

CHAPTER 4

The efficacy of physical activity interventions in reducing antisocial behavior: a meta-analytic review

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Journal of Experimental Criminology, 2022

Abstract

Objectives

This systematic review and meta-analysis examines the efficacy of physical activity interventions in the reduction of antisocial behavior in children and adults. Several possible moderators including study design, sample characteristics (age, proportion male, and sample type), control group, and outcome characteristics (type of activity, duration, frequency) were also investigated.

Methods

A literature search was performed in the following databases: PubMed, Ebsco/SportDiscus, Ebsco/APA PsycINFO, Ebsco/ERIC, Ebsco/Criminal Justice Abstracts, Embase.com, Clarivate Analytics/Web of Science Core Collection from inception to June 2021. Studies were eligible if they reviewed the effect of chronic physical activity interventions on antisocial behavior compared to waitlist, no-exercise, or attention control samples. The following studies were excluded: Animal studies, studies reporting on acute exercise, studies including yoga or mindfulness as sole measure of physical activity, and studies including substance (ab)use and/or smoking as only outcome measure. A random effects model was used to calculate pooled effect sizes. Risk of bias was assessed using the Cochrane Risk of Bias tool (version 2).

Results

The search yielded 29 studies, of which 20 were included in the meta-analysis. Results indicate a significant small-to-medium effect (g = -0.26) with a 95% confidence interval ranging from -0.48 to -0.04 in favor of physical activity interventions. Significant moderators included type of control group, type of physical activity, and type of antisocial behavior, with larger effect sizes for comparisons with inactive control groups (g = -0.31), interventions containing walking, jogging, or running as main type of physical activity (g = -0.87), and anger/hostility as antisocial outcome measure (g = -0.42).

Conclusions

Physical activity interventions may be a promising way to reduce antisocial behavior in children and adults. However, due to the overall high risk of bias in the included studies, more sound evaluation research is needed to better understand the functioning and to improve possible implementation of physical activity interventions.

Introduction

Antisocial behavior is a heterogeneous group of behaviors, including criminal offenses, aggression, and conduct problems. These types of behavior violate societal rules or the rights of others (Moffitt, 2017) and affect both perpetrator and victim (Cohen & Piquero, 2009; Heap, 2021). Conventional treatments aimed at reducing antisocial behavior mostly rely on cognitive behavioral theory (Bennett & Gibbons, 2000), yet with limited efficacy (Bennett & Gibbons, 2000; Dodge & McCourt, 2010; Frick, 2016; Lipsey & Cullen, 2007; Reid & Gacono, 2000). Re-offending rates after treatment are at 60% or higher (Fazel & Wolf, 2015; van der Put et al., 2016) and non-completion rates (i.e., percentage of participants dropping out before treatment completion) range from 20% to 40% (Rubin et al., 2007), indicating the need for additional interventions.

One proposed alternative intervention encompasses physical activity (i.e., any skeletal muscle-induced movement requiring energy expenditure) (Caspersen et al., 1985). Physical activity interventions may offer an accessible and inexpensive substitute for current interventions with multiple health benefits, including improved physical and mental well-being (Daskalopoulou et al., 2017; Lubans et al., 2012; Paluska & Schwenk, 2000). Physical activity has been suggested to improve several facets related to antisocial behavior, including enhanced self-control and emotion regulation (Boat & Cooper, 2019), greater feelings of social inclusion (Perks, 2007), and a more positive self-identity and self-worth (Bowker, 2006; Liu et al., 2015). Physical activity programs have been increasingly used by local governments and institutes (e.g., prisons, youth offender institutions) worldwide to rehabilitate offenders and prevent maladaptive or problematic behavior (Ekholm et al., 2013; Hartmann & Depro, 2006; Jones-Palm & Palm, 2005; Kelly, 2013; Makkai et al., 2003; Meek, 2018; Nelson et al., 2006; Nichols, 2010; Taylor et al., 2015), yet their effectiveness remains largely unclear.

To date, two previous meta-analytic reviews have examined the effect of physical activity on externalizing behavior in youth (Harwood et al., 2017; Spruit et al., 2016). The first review investigated the effect of martial arts on the reduction of aggression, anger, and violence in youth aged < 18. The authors included 12 studies with a comparison group, but no randomized controlled trials (RCT). They found an average significant effect of martial arts on aggression, but only after removing the three studies that consisted of one-time comparisons (as opposed to interventional, longitudinal, and cross-sectional studies) (Harwood et al., 2017). The second meta-review quantified the effect of physical activity interventions on four psychosocial outcomes, including externalizing problems (i.e., aggression, delinquency, or other conduct problems) in adolescents (aged 10-21). A study was included if a considerable part of the intervention included sports or (aerobic) exercise and the design was experimental (i.e., comparison group available). They found a significant small-to-moderate effect of physical activity interventions on the reduction of externalizing problems, with larger effect sizes for comparisons with other types of intervention (i.e., psychosocial or other leisure activities) and no effect for comparisons with waitlist or no-treatment groups (Spruit et al., 2016).

Regarding adult populations, the effect of physical activity interventions has only been previously examined in adults assessed through the Diagnostic and Statistical Manual of Mental Disorders (DSM: (American Psychiatric Association, 2014)) as nicotine, alcohol, and illicit drug (e.g., heroin, cocaine) abusers (Wang et al., 2014). The authors included 22 RCTs on physical activity (including aerobic exercise, resistance training, and mind-body exercises such as yoga, tai chi, and qi gong). They found physical activity interventions to significantly decrease withdrawal symptoms and increase abstinence rates, with larger effects in illicit drugs users compared to nicotine and alcohol abusers (Wang et al., 2014). However, 30% of the included studies (n = 7) contained elements of mindfulness (Auty et al., 2017), classifying mind-body exercises such as yoga and qi gong as physical activity. Mindfulness has been shown to be effective in the reduction of antisocial behavior (Gillions et al., 2019; Tao et al., 2021) and thus the question remains if physical activity without mindfulness can elicit the same results in adults.

Recently, a meta-analytic review was published on the effect of sports programs on crime-related outcomes including reconviction, drug use, anger, self-control, and impulsivity in a sample containing both children and adults (Jugl et al., 2021). Studies were eligible if the design was quasi-experimental or an RCT. The authors analyzed 10 studies in individuals at risk of (re)-offending or from the general population, if the program was designed to prevent criminal behavior (mean age 25, age range 7–59 years). Martial arts programs, outdoor activities, and adventure activities were excluded, but no other restrictions were put on type of sports program. Their results indicate a significant positive effect on criminal behavior with no moderating effect of program, sample, or study characteristics.

Although previous reviews suggest a positive effect of physical activity on antisocial behavior, they do not address the heterogeneous nature of antisocial behavior (Popovici et al., 2014) or they are limited due to methodological issues. Specifically, the existing meta-review on martial arts (Harwood et al., 2017) did not account for elements of mindfulness associated with martial arts (Miyata et al., 2020) which may have affected results (Gillions et al., 2019; Tao et al., 2021). In addition, the inclusion of cross-sectional studies hampers causal statements regarding the effect of physical activity (Harwood et al., 2017). Furthermore, the meta-analysis of Spruit et al. (Spruit et al., 2016) on physical activity interventions contained a relatively small number of studies (n = 14) which may have limited generalizability. They also examined three other interrelated psychosocial outcomes (internalizing problems, academic achievement, and self-concept). As the authors state, results of the individual meta-analyses should therefore not be interpreted independently due to the high level of interrelatedness (Spruit et al., 2016). Finally, both meta-analytic reviews were limited to adolescents or young adults (aged < 21). Thus far, only Jugl and colleagues included both children and adults, yet most of their sports programs specifically aimed to promote personal development (e.g., improving prosocial behavior and self-confidence) rather than to improve fitness parameters (Jugl et al., 2021). This resulted in the inclusion of a range of activities that were not always related to physical activity, such as reading and numeracy lessons. Furthermore, 2 studies examined the effects of yoga (containing mindfulness: (Auty et al., 2017)) which could have affected the results as described earlier. In summary, the effects of physical activity on antisocial behavior in both children and adults remain unclear.

As existing physical activity programs target both youth and adults (Ekholm et al., 2013; Hartmann & Depro, 2006; Jones-Palm & Palm, 2005; Kelly, 2013; Makkai et al., 2003; Meek, 2018; Nelson et al., 2006; Nichols, 2010; Taylor et al., 2015), it is important to assess efficacy across different age groups. Moreover, due to the highly heterogeneous nature of antisocial behavior, it is possible that not all types of antisocial behavior are affected similarly by physical activity interventions, depending on the underlying reason for the displayed behavior. For example, aggressive tendencies may be acquired through social learning, such as conditioning and observation (Bandura, 1973) whereas hostility is defined as an emotional state (Tsikandilakis et al., 2019). Thus, different effects may be expected. This is illustrated by a study where an additional after-school volleyball program significantly improved physical and verbal aggression and anger, but not hostility in adolescents, compared to a no-intervention control sample (Trajkovíc et al., 2020). Similarly, different types of physical activity interventions may have different impacts. For example, one study found positive effects on hostility after high-intensity strength training but no effect after cardiovascular plus resistance training in prisoners (Battaglia et al., 2015). To date, no meta-review exists on the effect of physical activity that considers the possible effects of both a heterogeneous predictor and outcome.

The current meta-analysis attempts to fill this gap by examining the efficacy of physical activity interventions in the reduction of antisocial behavior (e.g., aggression, externalizing behavior, delinquency, hostility, anger, and other maladaptive or disruptive behaviors) in both children and adults. By addressing a broader range of antisocial behavior and physical activity interventions (excluding elements of mindfulness) and only including RCTs and (quasi)-experimental designs, the present review aims to take the next step in research on physical activity as a treatment reducing antisocial behavior. In addition, by coding and analyzing multiple possible moderators (Spruit et al., 2016) including study design, operationalization of outcome, type of physical activity, and sample characteristics, we hope to gain more insight into who could benefit most from physical activity interventions, and how. This may aid in the individual tailoring of interventions, possibly increasing treatment efficacy (Frick, 2016; Rubin et al., 2007). To increase generalizability and comparability between outcome measures (Hofer & Piccinin, 2009), we did not include studies on nicotine and substance (ab)use. Physical activity interventions included all interventions for children and adults in which sports and/or (aerobic) exercise were the main treatments. We focused on chronic (i.e., regular) (Guiney & Machado, 2013) physical activity as opposed to acute (i.e., a single bout) physical activity (Chang et al., 2012).

Methods

Literature search

This meta-analytic review was conducted and reported following the Preferred Reporting Items for Systematic reviews and Meta-analysis (PRISMA) guidelines (Page et al., 2021). A comprehensive search was performed in the databases: PubMed, Ebsco/SportDiscus, Ebsco/APA PsycINFO, Ebsco/ERIC, Ebsco/Criminal Justice Abstracts, Embase.com, Clarivate Analytics/Web of Science Core Collection, from inception to June 28th, 2021 in collaboration with a medical information specialist (JCFK). The search included controlled terms and free text terms for synonyms of "exercise" or "sports" combined with synonyms of "aggression" or "antisocial" and "young adult" and "RCTs" or "SRs" or "cohort studies", with the exclusion of "animal studies" or specific terms like "spectator aggression". The search was performed without restrictions for date or language. Duplicate articles were excluded by a medical information specialist (JCFK) using Endnote X20.0.1 (Clarivate^{tm}), following the Amsterdam Efficient Deduplication (AED)-method (Otten et al., 2019) and the Bramer-method (Bramer et al., 2016). This review is registered in the systematic review registry Prospero (registration number: CRD42020198123). We did not prepare a review protocol.

Selection criteria

The eligibility of included studies was assessed using the web-based program Rayyan (Ouzzani et al., 2016) with the following criteria: (a) participants from general or clinical populations; (b) the intervention involved any chronic physical activity intervention; (c) controls were either waitlist, no-exercise, or attention control groups; (d) outcome measures were related to antisocial behavior including self-report and observational measures; (e) the design permitted the computation of a reliable effect size, i.e., RCT or quasi-experimental design with a control group; (f) post-intervention outcome measures were obtainable; and (g) the study was published in English or Dutch or translations were obtainable. Animal studies were excluded, as were studies reporting only on the effect of acute exercise, studies including yoga or mindfulness as a measure of physical activity, studies including substance (ab)use and/or smoking as only outcome measure, and studies without a control sample. Gray literature, e.g., conference abstracts, posters, and theses, was searched and included if relevant. The first and second author screened all records (i.e., abstracts and full texts) for eligibility independently. Any discrepancies between the reviewers were resolved by a third author. In the case of missing data, the original authors were contacted.

Coding the data and potential moderators

Information on study design, sample characteristics, intervention characteristics, and outcome measures was coded by the first author and discussed with the second author to test possible moderators (Lipsey & Wilson, 2001). Study design was coded as RCT or quasi-experimental, since the latter may be more prone to bias and show larger effect sizes (MacLehose et al., 2000). In addition, the control group was coded as active (i.e., sedentary-attention, receiving the same amount of interpersonal interaction without a physical activity intervention) or inactive (i.e., waitlist or no intervention), as this might influence the expected effect of the intervention (Spruit et al., 2016).

Regarding sample characteristics, the proportion of males (Fredricks & Eccles, 2008; Wong et al., 2013), mean age (Park et al., 2017), and sample type (Özer et al., 2012) were coded and included as possible moderators. Sample type was coded as students, clinical (i.e., receiving care, diagnosed by a clinician, or meeting criteria without a diagnosis), offenders, and other (i.e., sedentary students and university faculty (i.e., no regular physical activity in the preceding year as determined by the Leisure Time Physical Activity questionnaire), students with overweight (i.e., ≥85th percentile body mass index), students receiving special education, and students with a high risk of offending). Sedentary and overweight students were separated from the students' category as these characteristics have previously been shown to have a positive association with antisocial behavior such as anger and aggression (Hasler et al., 2004; Malmir & Nedaee, 2019). Thus, as these students may show elevated levels of antisocial behavior at baseline, different treatment effects may be expected compared to students who are not sedentary or overweight. This also applies to the other two groups, i.e., students receiving special education (Dickson et al., 2005) and students identified with a high risk of offending (Spruit et al., 2018). Age and the proportion of males were scored continuously.

Several intervention characteristics were also coded, i.e., type of physical activity, duration, and frequency of the intervention. Type of physical activity was first coded as string, and later subdivided based on existing data in aerobic exercise, sports (e.g., swimming, volleyball, soccer), walking (including jogging and running), martial arts, and other types of physical activity (i.e., dancing, weightlifting, or mixed). It is expected that different types of physical activity elicit different treatment effects (Battaglia et al., 2015; Lubans et al., 2012). Additionally, duration (in weeks) and frequency (minutes per week) of the intervention were coded, as these may influence the strength of the effect of physical activity interventions (Taylor et al., 2015).

Lastly, the outcome measure was coded based on the data as problem behavior (i.e., general antisocial behavior including externalizing behavior), externalizing behavior (i.e., rule-breaking and aggressive behavior), disruptive classroom behavior (i.e., problematic behavior in a classroom setting, including disciplinary referrals), aggressive behavior, anger expression, and hostility.

The risk of bias was assessed with the Risk of Bias tool (RoB 2: (Sterne et al., 2019)). This tool addresses five domains: randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result. The risk of bias in these domains was estimated as low risk, some concerns, or high risk. The first author assessed the risk of bias. The results were then discussed with the second author. Any disagreements were solved with a third author.

Effect size calculation and analysis

Pre- and post-intervention means and standard deviations were extracted to calculate standardized mean differences (SMDs) and standardized errors using Hedges' g statistic (Harrer et al., 2021). No study reported the correlation coefficient (*r*) between pre- and post-treatment scores needed to calculate the effect size. We, therefore, conducted sensitivity analyses imputing different values for *r* (Table S1 in supplement). As the results were similar, we used an estimate of r = 0.7, as recommended by Rosenthal (Rosenthal, 1991). If a study reported multiple outcome measures, only the best -validated outcome measure was included. If all measures were similarly validated, the field's most use was selected to calculate an effect size, to prevent violation of the assumption of independent effect sizes. All analyses were performed using R version 4.0.4. Effect sizes were calculated using the "escalc" function within the metafor-package (Viechtbauer, 2010) and reported in Hedges' *g* (Hedges, 1981). We also reported several measures of heterogeneity (I^2, tau^2, and the prediction interval) (Borenstein et al., 2007; IntHout et al., 2016). We queried the authors of 9 studies to obtain missing information. In total, 7 authors responded, of which 2 replied that the data could not be obtained. Thus, additional data was received for 5 studies. They were included in the meta-review.

Meta-regression and subgroup analyses were performed with the meta- (Balduzzi et al., 2019) and metafor-packages (Viechtbauer, 2010) using a random effects model (as between-study heterogeneity was expected). Heterogeneity was examined using I^2 as the proportion of observed effects-variation due to true effects-variation, tau^2 as the amount of heterogeneity in true effects, and the prediction interval as an estimation of the true effects in future studies (Borenstein et al., 2017; IntHout et al., 2016). A high I^2 indicates non-homogenous effect sizes meaning moderators or outliers should be identified. In contrast, a low I^2 may indicate homogenous effect sizes, with the I^2 interval as an index for the level of certainty for this result (Borenstein et al., 2017). The Knapp and Hartung adjustment (Knapp & Hartung, 2003) was used to calculate the corresponding confidence intervals (Inthout et al., 2014; Langan et al., 2019). Furthermore, to detect the individual contribution of each study to the heterogeneity, Baujat plots were used (Baujat et al., 2002). Possible outliers were detected using the "find.outliers" function of the dmetar-package (Harrer et al., 2021), which identifies studies for which the upper bound of the 95% confidence interval is lower than the lower bound of the pooled effect confidence interval, or for which the lower bound of the interval is higher than the upper bound of the pooled effect confidence interval. Next, we performed sensitivity analyses excluding these outliers, to examine the possible influence on effect size. Finally, publication bias (i.e., an overestimation of the true effect size due to the exclusion of unpublished studies with non-significant findings (Rosenthal, 1979)) was tested with funnel plot asymmetry according to Egger's method (Egger et al., 1997) and the trim and fill plot (Duval & Tweedie, 2000) using the "trimfill" function in the metafor-package (Viechtbauer, 2010). In the case of an asymmetrical funnel plot (indicating publication bias), the trim and fill procedure would correct this by imputing estimations of the missing effect sizes based on existing effect sizes. These estimations were then included in a new meta-analysis showing the influence of the missing effect sizes on the overall effect size.

Results

The search yielded 34,036 studies. After removing duplicates, 23,524 abstracts were screened, of which 162 studies were assessed for eligibility. No full-text was available for 33 articles, resulting in 129 full-text articles. After reading the full-text articles, 102 additional reports were excluded (See Figure 1 for exclusion reasons). The two most common exclusion reasons were study design (n = 32), e.g., observational or case study; and no outcome measures related to antisocial behavior (n = 16), e.g., antisocial behavior was mentioned but not measured, or only measured at baseline. The current meta-analytic review consists of 29 studies, of which 20 reported on sufficient information to calculate effect sizes (6 studies did not report on post-treatment scores, and 3 additional studies did not report on pre-treatment scores). The flow chart of the selection process is visualized in Figure 1.

Basic characteristics of studies

An overview of the basic characteristics can be found in Table 1. A total of k = 29 studies were included in the systematic review, of which k = 20 reported sufficient information to calculate effect size (3 studies only reported on post-treatment means). Thus, for the meta-analysis, we report on k = 20 studies that include N = 2250 participants. In total, n = 1209 participated in a physical activity intervention and n = 1041 served as control group (of whom 1171 participants received no intervention or were placed on a waitlist and 32 participants received a sedentary-attention intervention). Eight studies included students from the general population (3 included elementary school students and 5 included high school students) and 6 studies included students receiving care (n = 1) or meeting criteria for a behavioral disorder (n = 5). One study reported on sedentary high school students and university faculty, one on low level or special education students, one on high school students with overweight, and three studies reported on an offender population. Five interventions were aerobic-based exercises; 6 were (team) sports (e.g., soccer, swimming, volleyball); 2 included walking, jogging, or running, 3 were based on martial arts; 3 were mixed (i.e., martial arts and sports, strength and running, and exercises with resistance training); and 1 included weightlifting. The intervention duration ranged from 2.5 weeks to 39 weeks with a frequency varying between multiple daily sessions to single weekly sessions. Included outcome measures were aggressive behavior (n = 7), externalizing behavior (n = 4), anger expression (n = 3), disruptive classroom behavior including disciplinary referrals (n = 2), hostile behavior, or a combination of externalizing, bullying, and other problematic behaviors (n = 2).

Of the remaining 9 studies not included in the meta-analysis, 6 described a significant positive effect of physical activity on antisocial behavior (Basile et al., 1995; Goldshtrom et al., 2011; Palermo et al., 2006; Pan, 2010; Yılmaz & Soyer, 2018; Zivin et al., 2001) and 3 studies could not find a significant effect (Bunketorp et al., 2015; Carter et al., 2017; Welland et al., 2020).

Figure 1 *Prisma flow diagram*

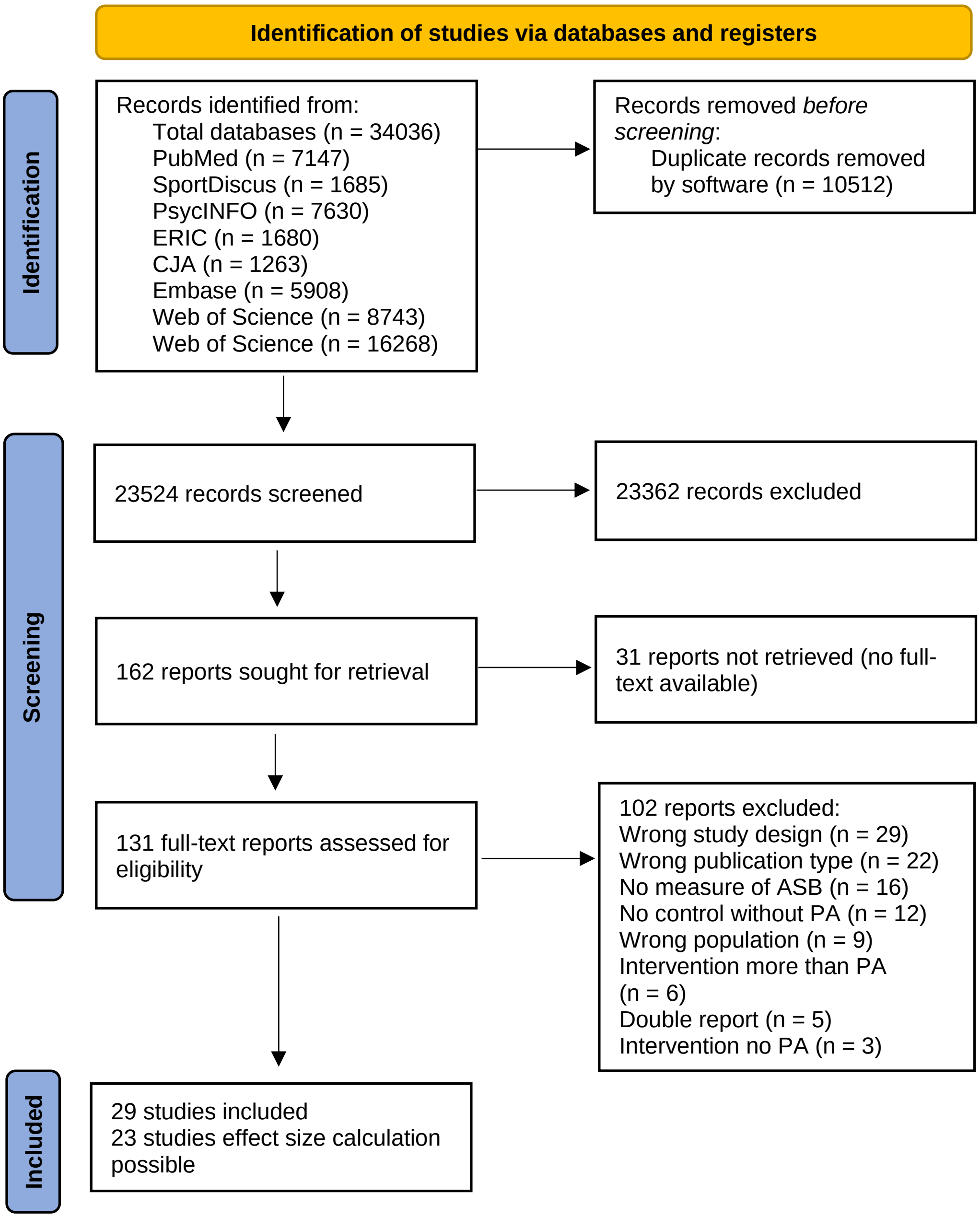


Figure adapted from the PRISMA 2020 statement (Page et al., 2021)

Table 1 Characteristics of included studies

Author	RCT	Control	N	% male	M age	population	type of PA	Frequency (min/wks)	Duration (wks)	type of ASB	Instrument
Effect size calculation possible (n = 23)											
Basile, 1995	yes	inactive (no PA or waitlist)	38	92	9.9	clinical	walk/jog/ run	80	4	disruptive classroom behavior	observations of disruptive classroom behavior
Battaglia, 2015	yes	inactive (no PA or waitlist)	42	100	31.4	offender	aerobic	120	39	hostility	Symptom Checklist-90-R
Bunketorp, 2015	no	inactive (no PA or waitlist)	349	52	9.9	student	aerobic	75	n/a	problem	Strengths and Difficulties Questionnaire
Bustamente, 2016	yes	active (sed-att)	35	69	9.1	clinical	sports	300	10	problem	Social Skills Improvement System
Delva-Tauiliili, 1995	no	inactive (no PA or waitlist)	42	100	10.5	student	martial arts	225	2.5	aggression	Rating scale to measure aggressive behaviors
Goldshtrom, 2011	no	inactive (no PA or waitlist)	33	49	8.5	clinical	other	12.5	8	aggression	Achenbach's Child Behaviour Checklist

Table 1 (continued)

Author	RCT	Control	N	% male	M age	population	type of PA	Frequency (min/wks)	Duration (wks)	type of ASB	Instrument
Greco, 2020	yes	inactive (no PA or waitlist)	28	86	9	clinical	martial arts	90	12	problem	Social Skills Improvement System
Harvey, 2018	yes	inactive (no PA or waitlist)	68	46	n/a	student	aerobic	100	40	disruptive classroom behavior	mean score on Learning Behavior Scale
Hilyer, 1982	yes	Inactive (tau)	43	100	17	offender	mixed	270	20	anger	Profile of Mood States
Norris, 1991	no	inactive (no PA or waitlist)	30	54	16.7	student	aerobic	60	10	hostility	Multiple Affect Adjective Check List
Ozer, 2008	yes	inactive (no PA or waitlist)	23	65	7.5	clinical	sports	90	14	externalizing	combined score on Child Behavior Checklist and Teacher Report Form

Table 1 (continued)

Author	RCT	Control	N	% male	M age	population	type of PA	Frequency (min/wks)	Duration (wks)	type of ASB	Instrument
Ozer, 2012	yes	inactive (no PA or waitlist)	38	100	14	student	sports	270	8	externalizing	combined score on Child Behavior Checklist and Teacher Report Form
Phung, 2021	yes	Inactive (no PA or waitlist)	34	82	9.3	clinical	martial arts	90	13	externalizing	Child Behavioural Checklist
Ramer, 2010	yes	Active (sed-att)	35	69	9.0	clinical	aerobic	450	10	disruptive classroom behavior	disciplinary referrals
Shachar, 2016	no	inactive (no PA or waitlist)	649	76	n/a	student	mixed	300	24	aggression	Buss & Perry Aggression Questionnaire
Spruit, 2018	no	inactive (no PA or waitlist)	231	88	14.4	other	sports	n/a	56	aggression	Buss – Durkee Hostility Inventory

Table 1 (continued)

Author	RCT	Control	N	% male	M age	population	type of PA	Frequency (min/wks)	Duration (wks)	type of ASB	Instrument
Tkacz, 2008	yes	inactive (no PA or waitlist)	208	43	9.7	other	aerobic	200	12.8	anger	Pediatric Anger Expression Scale
Trakjovic (a), 2020	yes	inactive (no PA or waitlist)	105	72	15.7	student	sports	90	35	aggression	Buss & Perry Aggression Questionnaire
Tse, 2020	yes	inactive (no PA or waitlist)	27	85	9.8	clinical	walk/jog/run	120	12	externalizing	Child Behavior Checklist
Wade, 2018	yes	inactive (no PA or waitlist)	289	100	12.7	student	mixed	51	35	aggression	Aggression Scale
Wagner, 1999	no	inactive (no PA or waitlist)	202	100	29.6	offender	other	90	8	aggression	Buss & Perry Aggression Questionnaire

Table 1 (continued)

Author	RCT	Control	N	% male	M age	population	type of PA	Frequency (min/wks)	Duration (wks)	type of ASB	Instrument
Effect size calculation not possible due to insufficient information (n = 6)											
Carter, 2016	no	inactive (no PA or waitlist)	111	45	8.5	student	aerobic	180	24	externalizing	combined score on Child Behavior Checklist and Teacher Report Form
Palermo, 2006*	no	inactive (no PA or waitlist)	16	82	8.5	clinical	martial arts	n/a	43	other	The Carey Temperament Scale
Pan, 2010*	no	inactive (tau)	16	100	7.2	clinical	sports	120	10	disruptive classroom behavior	School Social Behavior Scale
Welland, 2020	no	inactive (no PA or waitlist)	46	100	19.6	offender	sports	n/a	8	other	Measure of Criminal Attitudes and Associates
Yilmez, 2018*	yes	n/a	20	70	8	other	mixed	120	24	disruptive classroom behavior	School Social Behavior Scale
Zivin, 2001*	no	inactive (no PA or waitlist)	60	100	12.9	other	martial arts	135	10	disruptive classroom behavior	Sutter-Eyberg Student Behavior Inventory

Note. RCT = randomized control trial; Active PA = physical activity; wk = weeks, min/wk = minutes per week; ASB = antisocial behavior; sed-att = sedentary attention; tau = treatment as usual.

* = study reported significant effect of physical activity.

Of the studies reporting on a significant intervention effect, n = 4 included a clinical population (maltreated children (n = 1), children with a behavioral disorder (n = 2), boys with autism spectrum disorder (n = 1)), and n = 2 reported on other samples (children with mild intellectual disorder and boys at risk for antisocial behavior). The non-significant studies included elementary school students (n = 3), and offenders (n = 1). The type of physical activity in the significant studies was martial arts (n = 2), sports, i.e., swimming (n = 1), walking/jogging/running (n = 1), rhythmic exercises (n = 1), and mixed, i.e., balance and coordination play events (n = 1). For the non-significant studies, this included aerobic exercises (n = 2), and sports, i.e., rugby (n = 1). In the significant studies, 4 included measures of disruptive classroom behavior, one study included aggression, and one study included temperament. The non-significant studies examined externalizing behavior (n = 1), problem behavior (n = 1), and pro-criminal attitudes (n = 1).

Table 2 Overall effect of physical activity interventions on antisocial behavior

Study	*k*	Mean *d*	95% CI	*t*	*p*	I^2 (95% CI)
Overall effects						
Main analysis	23	-0.276	(-0.500; -0.052)	-2.56	.01	69.6 (53.5-80.2)
Sensitivity analysis excluding Harvey, 2018	22	-0.325	-0.508; -0.142)	-3.70	<0.001	57.6 (32.0-73.6)

Note. *k* = number of studies; Mean *d* = mean effect size (*d*); CI = confidence interval.

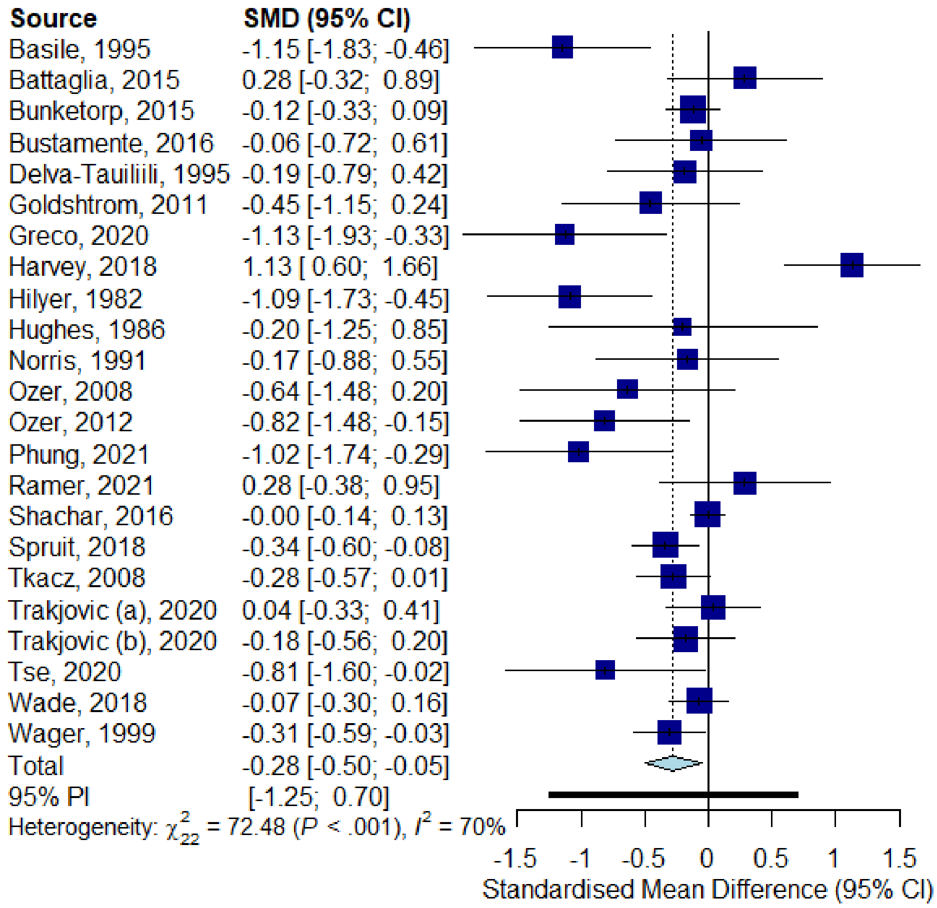
Efficacy of physical activity

Pooled effect sizes were calculated with a random effects model (see Table 2). We found an overall significant small-to-medium effect (g = -0.26), representing a reduction of antisocial behavior after physical activity interventions versus no physical activity intervention, waitlist, or attention-control. The trim-and-fill plot (Figure S1 in supplement) and Egger's test (intercept = 0.96, 95% CI = -1.09; -2.91, t = 0.89, p = .386) did not indicate publication bias. The substantial percentage of variability in effect sizes (I^2 = 82.5) indicated possible moderators or outliers. Furthermore, the prediction interval ranged from g = -1.18 to 0.66, indicating the effect of physical activity in future studies may be beneficial or not beneficial. Three outliers were detected: Harvey et al., (2018); Phung et al., (2021); and Shachar et al., (2016). Results from the sensitivity analysis excluding these outliers are reported in Table 2. Removing the outliers resulted in moderate-substantial heterogeneity (I^2 = 63.5) and small-to-medium effect size (g = -0.24). The prediction interval ranged from g = -1.17 to 0.70. Examination of the Baujat plot (supplement: Figure S2) identified Shachar et al., (2016) as adding substantially to the heterogeneity as well as highly influencing effect size, possible due to the large N. A second sensitivity analysis was performed removing only Shachar et al., (2016), see Table 2. This reduced the effect size slightly (g = -0.23) with a prediction interval ranging from g -1.17 to 0.70. A forest plot was created excluding all outliers ((Harvey et al., (2018); Phung et al.,(2021); and Shachar et al., (2016)), see Figure S3 in supplement.

Due to the expected small sample size, we included studies where physical activity was the main treatment, but a significantly smaller part included non-physical activity treatment. Specifically, Hilyer et al., (1982) included 10-15 min counseling mostly related to fitness and health, Phung et al., (2021) included a 5-minute bowing and mindfulness exercise, and Wade et al., (2018) included 3 x 20 min interactive seminars on screen time. To examine if this influenced our effect size, a third sensitivity analysis was performed excluding these three studies. Removing these studies did not result in large deviations, as shown in Table 2 (g = -0.22 with a prediction interval ranging from g -1.08 to 0.64).

Lastly, because three studies only reported on post-treatment means, we ran a supplementary analysis using post-treatment scores without correction for pre-treatment scores. Results are similar, with k = 23, g = -0.27, p = .02, and a prediction interval ranging from g -1.18 to 0.66 (see Appendix, Table S2).

Figure 2 Forrest plot of main analysis



Moderator analysis

Nine moderator analyses were performed (Table 3). Due to small subgroups and overlapping constructs, we combined problem behavior with externalizing behavior, and anger expression with hostility. Significant moderating effects were found for type of control group, type of physical activity intervention, and type of antisocial outcome. Specifically, we found a larger effect of physical activity interventions (g = -0.31, k = 18) compared to control groups that did not receive any intervention, but no significant effect (g = 0.25, k = 2) compared to sedentary attention or other types of interventions not containing elements of physical activity (e.g., psychosocial treatment). Furthermore, we found a significant moderating effect of type of physical activity, with larger effects for interventions containing walking, jogging, or running (*g* = -0.87, *k* = 3) but non-significant effects for aerobic exercise (*g* = 0.05, *k* = 5), sports (*g* = -0.04, *k* = 6), martial arts (*g* = -0.713, *k* = 3), or other types of physical activity (e.g., weightlifting or dancing; *g* = -0.33, *k* = 3). Lastly, we found a larger effect size on anger and/or hostility as antisocial outcome (*g* = -0.42, *k* = 5), but no significant effect on other types of antisocial behavior, i.e., aggressive behavior (*g* = -0.21, *k* = 7), problem and/or externalizing behavior (*g* = -0.48, *k* = 6), and disruptive classroom behavior (*g* = 0.45, *k* = 2). Study design, sample characteristics (age, proportion male, sample type), intervention frequency (in weeks), and intervention duration (in weeks) did not significantly moderate the effect of physical activity on antisocial behavior. Caution is advised interpreting these results, due to the limited amount of studies in some of the comparison groups (i.e., active control groups and interventions containing walking, jogging, and/or running).

Table 3 Moderator analyses

Study	*k*	Mean *d*	95% CI	t	p	I^2 (95% CI)	P_{sg}
Study design	23						.356
RCT	16	-0.321	(-0.661; -0.018)	-2.02	.061	76.3 (61.7; 85.4)	
Quasi experimental	7	-0.165	(-0.308; -0.022)	-2.82	.030	27.7 (0.0; 68.7)	
Control group	23						.040*
Inactive (no intervention, treatment as usual, waitlist)	21	-0.310	(-0.549; -0.071)	-2.71	.013*	71.7 (56.2; 81.8)	
Active (sedentary attention, other intervention)	2	0.112	(-2.060; 2.284)	0.66	.630	0.0	
Sample							
Age (continuous)	21	-0.574	(-1.004; -0.144)	-2.79	.011	71.1	.237
Proportion male (continuous)	23	0.471	(-0.389; 1.332)	-1.13	.267	83.8	.077
Sample type	23						.133
student	9	-0.029	(-0.392; 0.333)	-0.19	.854	69.2 (38.5; 84.6)	
clinical	8	-0.602	(-1.046; -0.158)	-3.21	.014	53.6 (0.0; 79.1)	
offender	3	-0.361	(-2.014; 1.290)	-0.94	.445	78.5 (30.9; 93.3)	
other	3	-0.307	(-0.416; -0.198)	-12.09	.006	0.0 (0.0; 89.6)	
Intervention							
Intervention type	23						.029*
Aerobic exercise	6	0.165	(-0.381; 0.712)	0.78	.471	79.2 (54.4; 90.5)	
Sports-related	6	-0.271	(-0.584; 0.041)	-2.23	.076	27.0 (0.0; 69.7)	

Table 3 (continued)

Study	*k*	Mean *d*	95% CI	t	p	I^2 (95% CI)	P_{sg}
Walk/jog/run	3	-0.806	(-1.918; 0.306)	-3.12	.08*	8.1 (0.0; 90.4)	
Martial arts	3	-0.731	(-2.045; 0.570)	-2.42	.136	56.2 (0.0; 87.5)	
other	5	-0.305	(-0.800; 0.195)	-1.71	.161	71.9 (29.2; 88.9)	
Study	*k*	Mean *d*	95% CI	t	p	I^2 (95% CI)	P_{sg}
Outcome							.098
Aggressive behavior	8	-0.144	(-0.278; -0.011)	-2.57	.037	23.4 (0.0; 64.9)	
Problem and/or externalizing behavior	7	-0.571	(-0.978; -0.163)	-3.43	.014	62.2 (13.9; 83.4)	
Anger and/or hostility	5	-0.293	(-0.913; 0.326)	-1.31	.259	58.0 (0.0; 84.4)	
Disruptive classroom behavior	3	0.102	(-2.754; 2.959)	0.15	.891	92.4 (81.1; 97.0)	

Note. RCT = randomized controlled trial; *k* = number of studies; Mean *d* = mean effect size (*d*); CI = confidence interval; sg = subgroup.

* $p < .05$; ** $p < .01$

Risk of bias

The Cochrane risk of bias tool was used to assess the risk of bias in several domains (Sterne et al., 2019). As this tool is designed for RCTs, studies with a quasi-experimental design will always be classified as having at least some concerns. The current meta included 5 studies with a quasi-experimental design, of which 2 studies were judged as having a high risk of bias as it was unclear if they adopted adequate matching procedures in an attempt to decrease risk of bias. Regarding deviations from intended interventions, lack of published trial protocols hampered assessment, introduced bias in most studies. Missing outcome data was a problem for 11 studies, of which 1 study raised some concerns and 10 studies were assessed as having a high risk of bias. This was due to an unclear description of handling the missing data (e.g., controlling for possible bias, sensitivity analysis). All studies were judged to have some concerns related to measurement of the outcome. This was the result of questionnaires with mostly non-blinded outcome assessors (i.e., self-report (n = 9), parents (n = 6), teachers (n = 3), or outcome assessors with unclear blinding (i.e., trained researchers (n = 1)). Knowledge of the intervention could have influenced their answers on the questionnaires, although this risk was assessed as unlikely (as the assessors would not gain any benefit from this). Information on analysis intentions was judged as not available in all studies, resulting in some concerns related to selection of the reported result for all included studies.

Discussion

The current meta-analytic review assessed the effects of physical activity interventions on several measures of antisocial behavior (i.e., aggression, externalizing behavior, delinquency, hostility, and anger) in children and adults. Overall, we found a significant effect size (*g* = -0.26) in favor of physical activity, indicating physical activity interventions can improve antisocial behavior. More specifically, the negative effect size implies on average antisocial behavior is decreased in participants receiving physical activity compared to participants not receiving this intervention (e.g., waitlist or sedentary attention-controls). A note of caution is due here since the estimated range of effect sizes of future studies includes both positive and negative effect sizes (prediction interval ranging from *g* = -1.18 to 0.66). Thus, although our current results suggest a beneficial intervention effect, future studies might find less positive or even detrimental effects. In addition, the substantial heterogeneity indicates the need for more univariate measures of antisocial behavior, although removing three possible outliers resulted in moderate-substantial heterogeneity.

Our findings are partially consistent with previous meta-analyses in youth. Physical activity has previously been shown to be similarly effective (*d* = 0.32) in reducing antisocial behavior (i.e., aggression, delinquency, or other conduct problems) in adolescents (Spruit et al., 2016). In contrast, larger effect sizes (*d* = 0.65) were found in a review only including martial arts as physical activity, indicating a significant reduction in aggression in youth (Harwood et al., 2017). This may be due to the mindfulness components common to martial arts (Miyata et al., 2020) as mindfulness can effectively reduce antisocial behavior (Gillions et al., 2019; Tao et al., 2021), possibly through decreased rumination (Borders et al., 2010) and increased compassion (Lim et al., 2015). In our study, we did not find martial arts to be a significant moderator, yet caution is advised as we only included three studies with this type of activity (Delva-Tauiliili, 1995; Greco & de Ronzi, 2020; Phung & Goldberg, 2021). Thus, it is possible that interventions containing martial arts may result in larger reductions in antisocial behavior, but further research is needed to test this.

To the authors' knowledge, in adults, no meta-analytic review exists on the effect of physical activity on antisocial behavior, yet related externalizing behavior (i.e., substance abuse (Wang et al., 2014)) has been investigated. Physical activity interventions including mindfulness (e.g., martial arts or yoga) significantly reduced withdrawal symptoms (*d* = -1.24) and increased abstinent rate (odds ratio = 1.69) in adult substance abusers (Wang et al., 2014). As in our meta-analysis, the authors did not find a moderating effect of type of activity (aerobic versus mind-body). However, it should be noted that even though 30% of the included studies had mindfulness components, their comparisons contained only 3 and 2 studies in the mind-body subgroup for withdrawal symptoms and abstinence rate, respectively. Therefore, it is not possible to completely rule out the effects of mindfulness (Auty et al., 2017). In sum, there is evidence indicating that physical activity interventions (possibly with mindfulness) can be effective in the reduction of substance abuse in adults, yet comparison with our current results is complicated due to the possible interfering effect of mindfulness.

Similar to our findings, a recent meta-review found a moderate positive effect of sports programs (excluding martial arts programs and outdoor or adventure activities, but including yoga) on criminal behavior (e.g., reconviction, drug use, anger, self-control, and impulsivity) in favor of the sports programs (*d* = 0.36) in a sample containing both children and adults (Jugl et al., 2021). In line with our results, the authors could not find significant moderating effects for study design or sample characteristics. To our current knowledge, they did not examine any possible moderating effect for type of control group or intervention duration and frequency. They did not find an effect of type of physical activity but only looked at team sports versus individual versus combined sports, complicating the comparison with our categorization (Jugl et al., 2021). Somewhat surprisingly (due to the heterogeneous nature of their outcome measures) they also did not include type of outcome measure as a possible moderator. Despite these discrepancies, their results taken together with our findings indicate physical activity including sports programs can be beneficial (with a moderate effect) for both children and adults in the treatment and/or prevention of several measures of antisocial behavior.

In addition, we explored if the effect of physical activity on antisocial behavior was moderated by study design, sample characteristics, intervention characteristics, or outcome. Larger effect sizes were found for comparisons with controls not receiving any treatment compared to controls receiving a sedentary-attention treatment. This could indicate that the effect of physical activity may be partially explained by the received attention and interpersonal interactions (LaFave et al., 2019), but due to the small number of studies using a sedentary-attention control condition (k = 2), it is not possible to further interpret these results. Larger effects were also found for interventions containing walking, jogging, or running, yet no significant effects were found for other types of physical activity such as aerobic exercises or sports. Speculatively, this may be related to how difficult it is to master certain activities. It can be argued that compared to other types of activity (such as basketball or martial arts), walking, jogging, and running are easy to master, requiring no additional skill set or high cognitive control. As previous studies show robust associations between antisocial behavior and cognitive control deficits (Ogilvie et al., 2011) including high impulsivity (Gordon & Egan, 2010) and low self-control (DeLisi & Vaughn, 2011), it is possible that other types of activity are too demanding for participants to benefit from the positive behavioral effects. Lastly, we found a larger effect on anger and hostility as measures of antisocial outcome versus other types of antisocial behavior (e.g., externalizing behavior or aggression). Hostility and anger may be classified as more emotion-driven behavior (Tsikandilakis et al., 2019) compared to other antisocial constructs (which may be expressions of more learned behavior (Bandura, 1973). The effect of physical activity on anger and hostility might be the result of enhanced emotion regulation. This hypothesis is supported by (limited) existing research in clinical populations such as those suffering from multiple sclerosis (Bahmani et al., 2020) or children diagnosed with autism spectrum disorder (Tse, 2020). Although preliminary, these results indicate several important factors to address in future research to optimize the potential positive effects of physical activity interventions. To further examine their potential moderating effects, future research should include different types of control groups, measurements related to motivation, and differentiate between emotion-driven and acquired antisocial behavior.

Several limitations need to be acknowledged. First, none of the studies controlled for recreational physical activity during the intervention, which may have influenced treatment effects. However, these effects may be minimal due to the random assignment of treatments and comparison groups in 15 studies, and the instructions to continue normal physical activity during the intervention period in the other studies. Second, as only three studies reported on an adult sample, the generalizability to adults is limited, indicating the need for more (quasi-) experimental studies on adults. Third, antisocial outcomes were measured with a wide variety of instruments, which likely contributes to the high heterogeneity in the analysis. Lastly, the included studies were generally assessed as having a high risk of bias, complicating interpretations.

To summarize, these results demonstrate a negative effect size in favor of physical activity interventions in the reduction of several types of antisocial behavior. As physical activity is inexpensive and easy to administer, it may serve as a cost-effective treatment to improve multiple antisocial behaviors. However, due to the overall high risk of bias in the included studies and the level of variation in estimated future treatment effects, more sound evaluation research is needed to better understand the functioning and to improve possible implementation of physical activity interventions. Future studies should differentiate between types of control group, types of physical activity, and underlying causes of antisocial behavior, as these may significantly affect treatment outcome.

Supplement

Table S1 Sensitivity analysis using different coefficients for pre-post correlation (*r*)

Study	*k*	Mean *d*	95% CI	*t*	*p*	I^2 (95% CI)	tau^2 (95% CI)
r = 0.0	20	-0.259	(-0.467; -0.050)	-2.60	.01	46.7 (10.1; 68.4)	0.12 (0.00; 0.30)
r = 0.3	20	-0.258	(-0.472; -0.044)	-2.53	.02	62.0 (38.3; 76.6)	0.14 (0.02; 0.36)
r = 0.5	20	-0.259	(-0.477; -0.041)	-2.50	.02	72.2 (56.5; 82.2)	0.16 (0.04; 0.40)
r = 0.7	20	-0.262	(-0.484; -0.040)	-2.47	.02	82.5 (74.0; 88.2)	0.18 (0.06; 0.43)
r = 0.9	20	-0.266	(-0.492; -0.040)	-2.47	.02	92.9 (90.4; 94.8)	0.14 (0.02; 0.36)

Note. *r* = estimated pre-post correlation; *k* = number of studies; Mean *g* = mean effect size (Hedges' *g*); CI = confidence interval.

Figure S1 Trim and fill-plot

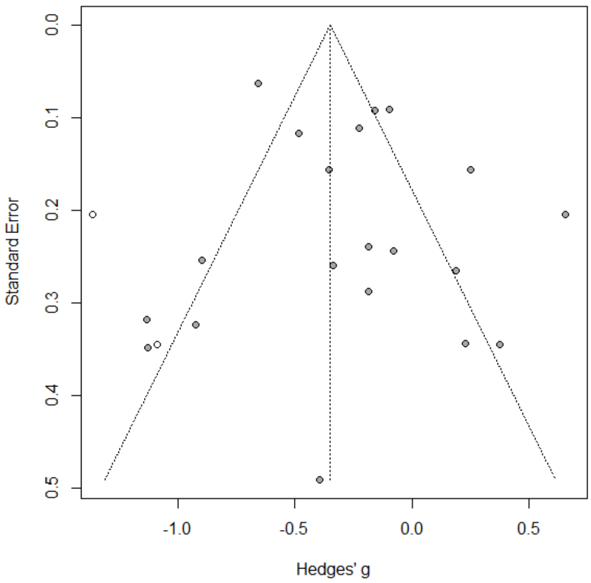


Figure S2 Baujat plot

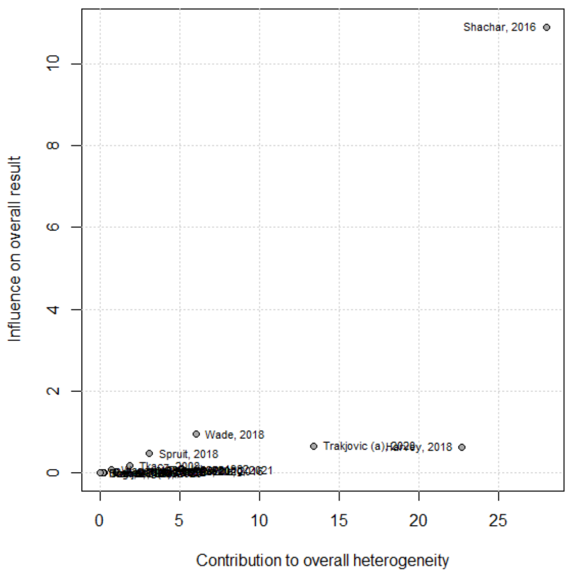


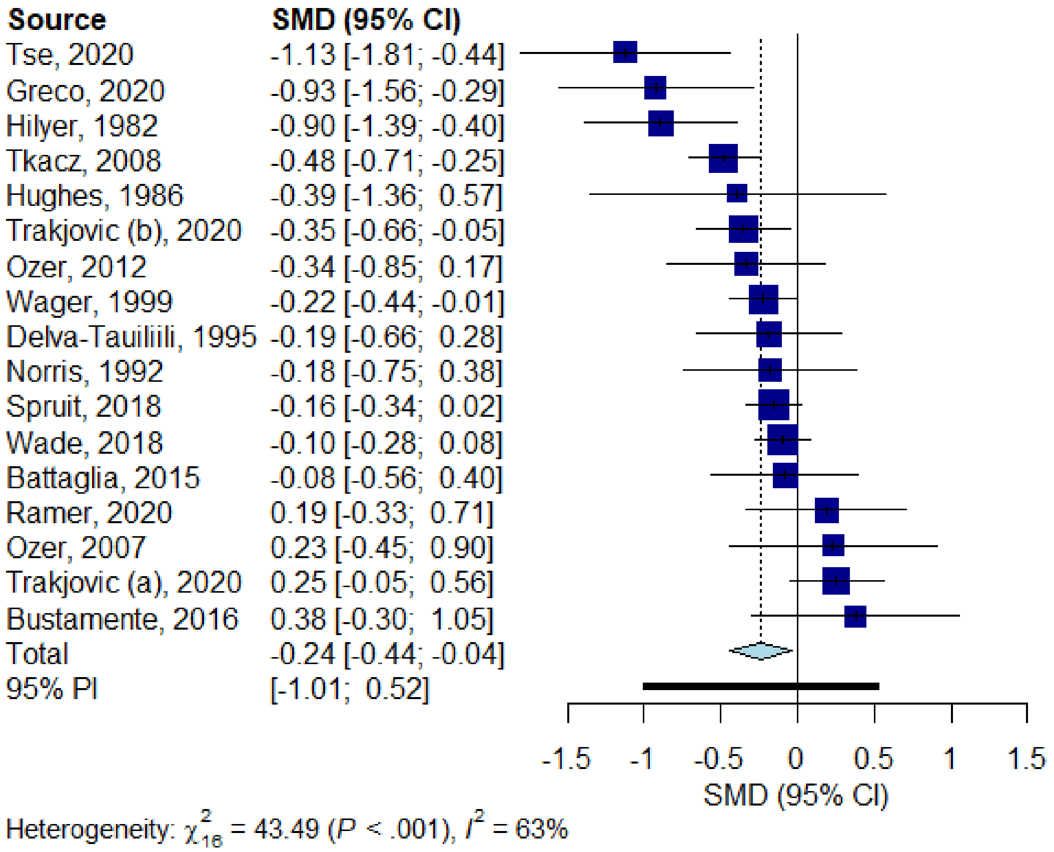
Table S2 Effect of physical activity interventions on antisocial behavior using only post-test means

Study	*k*	Mean *g*	95% CI	*t*	*p*	I^2 (95% CI)	tau^2 (95% CI)
Main analysis	23	-0.276	(-0.500; -0.052)	-2.56	**.01**	69.6 (53.5; 80.2)	0.20 (0.07; 0.47)

Note. *k* = number of studies; Mean *g* = mean effect size (Hedges' *g*); CI = confidence interval.

Bold values denote statistical significant *p*-values.

Figure S3 Forrest plot after removing three possible outliers (Harvey, 2018; Phung, 2021; and Shachar, 2016), weighed by study n and ordered by effect size



CHAPTER 5

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

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Frontiers in Human Neuroscience, 2022, *16*

Abstract

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.

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 (Bae et al., 2012; Baumgartner et al., 2018; Chaddock et al., 2010; Hillman et al., 2008; Kamijo et al., 2009; Kamijo & Takeda, 2009, 2010; Padilla et al., 2013, 2014; Pérez et al., 2014; van der Niet et al., 2015; Verburgh et al., 2014). 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; Marhe et al., 2013; Swann et al., 2009; Turner et al., 2018; Weidacker et al., 2017; Zeier et al., 2012). 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) versus non-users (M = 91) (Marhe et al., 2013) and in multi-problem young adults (M = 81, SD = 0.16) versus 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 (Giles et al., 2017; Goenarjo et al., 2020; Hogan et al., 2013; Pérez et al., 2014). Moreover, there is ample evidence that an increase in physical activity enhances cognitive control (Colcombe & Kramer, 2003; Gomez-Pinilla & Hillman, 2013; Guiney & Machado, 2013; Hillman et al., 2008; Smith et al., 2010; Verburgh et al., 2014), particularly in individuals with a sedentary lifestyle (Gomez-Pinilla & 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 (Daskalopoulou et al., 2017; Lubans et al., 2012; Paluska & Schwenk, 2000) including reduced risk of physical disorders (e.g., cardiovascular disease and obesity (Carnethon et al., 2003) and reduced risk of 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 min of vigorous-intensity physical activity per week (Bull et al., 2020; Riebe et al., 2018). Most young adults from the general population do not meet these recommendations (Marques et al., 2015; Song et al., 2013). 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 der Sluys et al., 2020; van Duin et al., 2017, 2018; Zijlmans et al., 2018, 2019, 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 & Pedersen, 2010) are associated with a sedentary lifestyle, yet lack of means of transportation (Spinney & 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 der Sluys et al., 2020; van Duin et al., 2017, 2018; Zijlmans et al., 2018, 2019, 2020). Due to mixed results in previous literature (Singh et al., 2008; Spinney & Millward, 2010; Stalsberg & 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; Marhe et al., 2013; Swann et al., 2009; Turner et al., 2018; Weidacker et al., 2017; Zeier et al., 2012), 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 on healthy young adults from the general population, we expect a positive association in the multi-problem group (Giles et al., 2017; Goenarjo et al., 2020; Hogan et al., 2013; Pérez et al., 2014).

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: (Luijks 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 of 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 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 & 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.

Table 1 Characteristics of multi-problem young adults and young adults from the general population

Variable	Multi-problem sample (N = 61) *M* (*SD*) / %	Age and sex-matched control sample (N = 62) *M* (*SD*) / %
Age	21.18 (2.77)	23.63 (2.71)
Highest finished education **		
No education	11.3%	0%
Primary education	24.2%	0%
Secondary pre-vocational education	29.1%	2.5%
Secondary senior education	3.2%	47.5%
Secondary vocational education	29.0%	9.5%
Higher education	0%	40.0%
Other	3.2%	0%
Ethnicity		
Western	19.4%	82.5%
Dutch Antilles	29.0%	0%
Moroccan	16.1%	5.0%
Surinamese	8.1%	0%
African	8.1%	1.3%
Cape Verdean	4.8%	0%
Syrian	3.2%	2.5%
Other	11.3%	8.8%
Daytime activities		
No daytime activities **	45.0%	3.7%
Work **	20.0%	70.7%
Education **	5.0%	58.5%
Care for others	3.3%	0%
Other **	26.7%	7.3%

Table 1 (continued)

Variable	Multi-problem sample (N = 61) *M* (*SD*) / %	Age and sex-matched control sample (N = 62) *M* (*SD*) / %
Family problems in youth		
No problems **	38.7%	17.1%
One parent (mostly) absent *	21.0%	7.3%
Mental health problems of family	4.8%	4.9%
Domestic violence *	14.5%	2.4%
Police contact of family members **	27.4%	0%
Drug use of family members *	12.9%	0%
Alcohol use of family members *	12.9%	1.2%
Other *	17.7%	2.4%
BSSS sensation seeking total	24.66 (4.83)	25.53 (6.08)
BIS-11 impulsivity total **	68.02 (9.44)	59.76 (8.73)
Alcohol and cannabis use		
Cannabis use past 30 days (unit) **	0.55 (0.50)	0.15 (0.35)
Alcohol use past 30 days (unit) **	0.26 (0.44)	0.63 (0.48)
Years of regular cannabis use **	3.38 (3.30)	0.40 (1.91)
Years of regular alcohol use *	1.34 (2.90)	3.35 (4.73)
Self-reported delinquency		
Destruction/public order offense -	60.7%	.
Property offense – lifetime	83.9%	.
Aggression/violent offense - lifetime	69.1%	.
Weapon offense – lifetime	45.5%	.
Drug offense - lifetime	64.3%	.
Self-reported police contact		
none	.	96.6%
Less than 1 contact per year	.	3.4%
Less than 1 contact per year	.	3.4%

Note. WODC = WODC Self-reported Delinquency Questionnaire; BSSS = Brief Sensation Seeking Scale; BIS-11 = Barratt Impulsiveness Scale
* $p < .05$. ** $p < .01$. *** $p < .001$

Cognitive control

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

Response inhibition was measured with a Go/NoGo task previously described in Zijlmans et al. (2021) and Luijten et al., (2013). 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 a 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. (Zijlmans et al., 2019). In short, participants were shown congruent and incongruent letter strings (HHHHH, SSSSS, HHSHH, 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 accurately 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 accurately 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 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 (EDC, 2019). 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 (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 body weight 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).

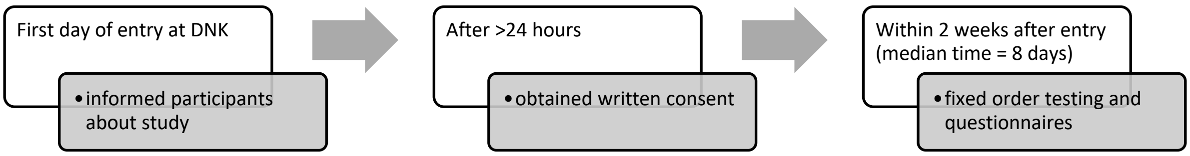
Because the association between physical activity and cognitive control may be influenced by body composition (Wiedemann et al., 2014) and intelligence (Hillman et al., 2005), we included Body Mass Index (BMI) and the score on a screener for low intelligence or a learning disability as control variables. BMI was measured by dividing self-reported height^2 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 color blindness.

Figure 1 Timeline of recruitment and testing



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 color blindness.

Statistical analyses

IBM SPSS Statistics for Windows version 20.0 (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 tests (p = .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 $p = .05$ 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 a side-by-side comparison of means.

In the explorative linear analysis within the multi-problem group (Table 2), 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). The first model containing only the covariates (SCIL, BMI) was not significant ($p = .849$, adj $R^2 = –.037$), nor was the model with the added cognitive control measures ($p = .225$, adj $R^2 = .059$). Results should be interpreted with caution due to the small sample size.

Discussion

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

	B	*SE (B)*	*p*	*t*	95% CI B Lower	Upper
Model 1						
Constant	8.235	0.901	<.001	9.140	6.420	10.050
BMI	-0.003	0.036	.941	-0.075	-0.075	0.069
SCIL	-0.016	0.027	.575	-0.565	-0.071	0.040
Model 2						
Constant	7.177	1.143	<.001	6.281	4.867	9.486
BMI	0.000	0.035	.997	-0.004	-0.071	0.071
SCIL	-0.047	0.030	.124	-1.573	-0.107	0.013
Stroop interference	-0.001	0.003	.821	-0.227	-0.006	0.005
Flanker total accuracy	1.360	1.324	.311	1.027	-1.317	4.036
Flanker post-error slowing	0.007	0.004	.070	1.858	-0.001	0.014
Flanker correctness effect	0.004	0.003	.176	1.377	-0.002	0.011
NoGo accuracy	.593	1.027	.567	0.577	-1.484	2.669

BMI = Body Mass Index (weight in kg / height in cm^2); SCIL = Screener for Intelligence and Learning Disabilities; Stroop interference = RT incongruent – RT congruent; Flanker post-error slowing = RT post error – RT post correct; Flanker correctness effect = RT correct – RT incorrect

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, 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 (Guthold et al., 2020; Valle et al., 2015) 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 (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 socio-economic status (SES) (Stalsberg & 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 on 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; Bergier et al., 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; Marhe et al., 2013; Swann et al., 2009; Turner et al., 2018; Weidacker et al., 2017; Zeier et al., 2012), 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)* (Cohen, 1988) were, respectively, large, small-medium, and medium-large in favor of the control group, 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 & 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 (Marhe et al., 2013; Ogilvie et al., 2011; Swann et al., 2009; Turner et al., 2018; Weidacker et al., 2017; Zeier et al., 2012). Cognitive control may be impaired due to co-existing disorders such as Attention-Deficit/Hyperactivity Disorder or autism spectrum disorder (Craig et al., 2016) or due to traumatic brain injury (Schretlen & Shapiro, 2003), which may be overrepresented in our sample of multi-problem young adults (Bellesi et al., 2019; Chester et al., 2022; Storebø & Simonsen, 2013). 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 (Ho et al., 2018; Kamijo & Takeda, 2009, 2010; Padilla et al., 2013, 2014; Pérez et al., 2014; 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 women, 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 & Kramer, 2003; Kamijo & Takeda, 2009, 2010) 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 of 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 versus healthy participants showed that a larger ISI resulted in better post-error slowing in the controls than a smaller ISI (Balogh & Czobor, 2014). 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 (Chaddock et al., 2010; Hillman et al., 2008; 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.

CHAPTER 6

The effects of six weeks of physical activity on cognitive control and trait impulsivity in multi-problem young adults: First findings of an RCT-study

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Arne Popma
Peter H. van der Laan
Erik J.A. Scherder

Submitted

Abstract

Objectives

To report the effect of a six-week light-active versus moderate-active physical activity intervention embedded in a multimodal day treatment program, on selected measures of cognitive control (i.e., response inhibition, error processing, and cognitive interference) and trait impulsivity.

Methods

A randomized controlled design including male multi-problem young adults (N = 23, aged 18-27).

Results

Cognitive control but not trait impulsivity improved over time, specifically improved inhibition, higher accuracy on an error-processing task, and improved (i.e., decreased) cognitive interference after six weeks. No interaction with physical activity intensity was found, suggesting similar treatment effects between intensity.

Conclusions

Overall, despite limitations (i.e., physical activity embedded in a larger treatment program, small sample size at follow-up, and low intervention adherence), these findings contribute to a growing body of evidence suggesting potential benefits of physical activity programs in the treatment of cognitive control deficits in at-risk populations, independent of exercise intensity.

Introduction

Executive functioning or cognitive control refers to a set of top-down processes critical for adaptive and goal-directed behavior, including working memory, cognitive flexibility, and inhibitory control (Diamond, 2013). Many other cognitive processes rely on this higher-order cognition (e.g., attention, learning, reasoning), and cognitive control deficits can therefore significantly disrupt these and other abilities (Botvinick & Braver, 2015; Fan, 2014). Executive dysfunctions have been previously found in clinical disorders such as autism spectrum disorder and attention-deficit/hyperactivity disorder (Craig et al., 2016). In addition, it has been related to antisocial and externalizing behaviors, e.g., aggression, substance use, and delinquency (Hiatt et al., 2004; Marhe et al., 2013; Swann et al., 2009; Turner et al., 2018; Weidacker et al., 2017; Zeier et al., 2012; Zijlmans et al., 2019). More specifically, compared to the general population, those displaying externalizing behavior have shown a relative inability to restrain inappropriate responses (i.e., response inhibition (Swann et al., 2009; Turner et al., 2018; Weidacker et al., 2017)), to adequately process errors (i.e., error processing (Marhe et al., 2013; Zijlmans et al., 2019)), and to suppress an automated response in favor of a less automated response (i.e., resistance to cognitive interference (Hiatt et al., 2004)). Given the widespread role of adequate neurocognitive functioning in our daily lives, it is important to search for effective interventions targeting these functions, such as increased physical activity (Álvarez-Bueno et al., 2017; Chen et al., 2020; Colcombe & Kramer, 2003; Gomez-Pinilla & Hillman, 2013; Guiney & Machado, 2013; Hillman et al., 2008; Smith et al., 2010; Stroth et al., 2009; Verburgh et al., 2014). Exploring the potential impact of physical activity on cognitive control may also contribute to our understanding of the mechanisms that link exercise and physical activity to reduced criminal and antisocial behavior adults (Holt, 2007; Meek, 2018; Nichols, 2010; Stern et al., 2019).

Cognitive control can be enhanced by increased regular physical activity (Álvarez-Bueno et al., 2017; Chen et al., 2020; Colcombe & Kramer, 2003; Gomez-Pinilla & Hillman, 2013; Guiney & Machado, 2013; Hillman et al., 2008; Smith et al., 2010; Stroth et al., 2009; Verburgh et al., 2014), with the most prominent results in healthy but sedentary individuals (Gomez-Pinilla & Hillman, 2013; Verburgh et al., 2014). Robust effects are found in healthy children (Álvarez-Bueno et al., 2017), adolescents (Liu et al., 2020), and older adults (Chen et al., 2020), yet information on healthy young adults is limited (for similar conclusions, see: (Hillman et al., 2008; Stillman et al., 2020; Verburgh et al., 2014)). This is especially true for young adults displaying externalizing behavior, regardless of the known advantages for these or similar populations (Jackson & Beaver, 2018). Related, studies are showing a decrease in antisocial behavior following physical activity interventions, including reduced aggression in youth (Harwood et al., 2017), reduced externalizing problems (e.g., aggressive and delinquent behavior) in adolescents (Spruit et al., 2016), and increased abstinence rate in adult substance abusers (Wang et al., 2014). These improvements in externalizing behavior in youth and adults may be the result of the enhanced ability to regulate and restrain one's behavior (i.e., exercise-induced neurocognitive changes) (Boat & Cooper, 2019; Holley et al., 2017). However, these effects are not fully understood in young adults (Stillman et al., 2020) and more research is needed in this age population.

To gain a better understanding of the effects of physical activity interventions on cognitive control, more rigorous study designs are needed, such as randomized controlled trials (RCTs). To date, however, very little research includes socially vulnerable or at-risk populations, despite the increased interest in exercise and sports programs to foster positive personal development, decrease antisocial behavior, and increase cognition in youth and young adults (Holt, 2007; Meek, 2018; Nichols, 2010; Stern et al., 2019). The aim of this study is therefore to report the first findings of an RCT on the effect of six weeks of light versus moderate physical activity embedded in a multimodal day treatment program, on selected measures of cognitive control in a sample of multi-problem young adults (Zijlmans et al., 2020). It is hypothesized that six weeks of moderate embedded physical activity leads to more improvements in cognitive control (indexed as response inhibition, error processing, and cognitive interference) (Colcombe & Kramer, 2003; Gomez-Pinilla & Hillman, 2013; Guiney & Machado, 2013; Hillman et al., 2008; Smith et al., 2010; Verburgh et al., 2014) and higher decreases in trait impulsivity (Ghahramani et al., 2016) compared to light physical activity.

Methods and Materials

Participants and treatment setting

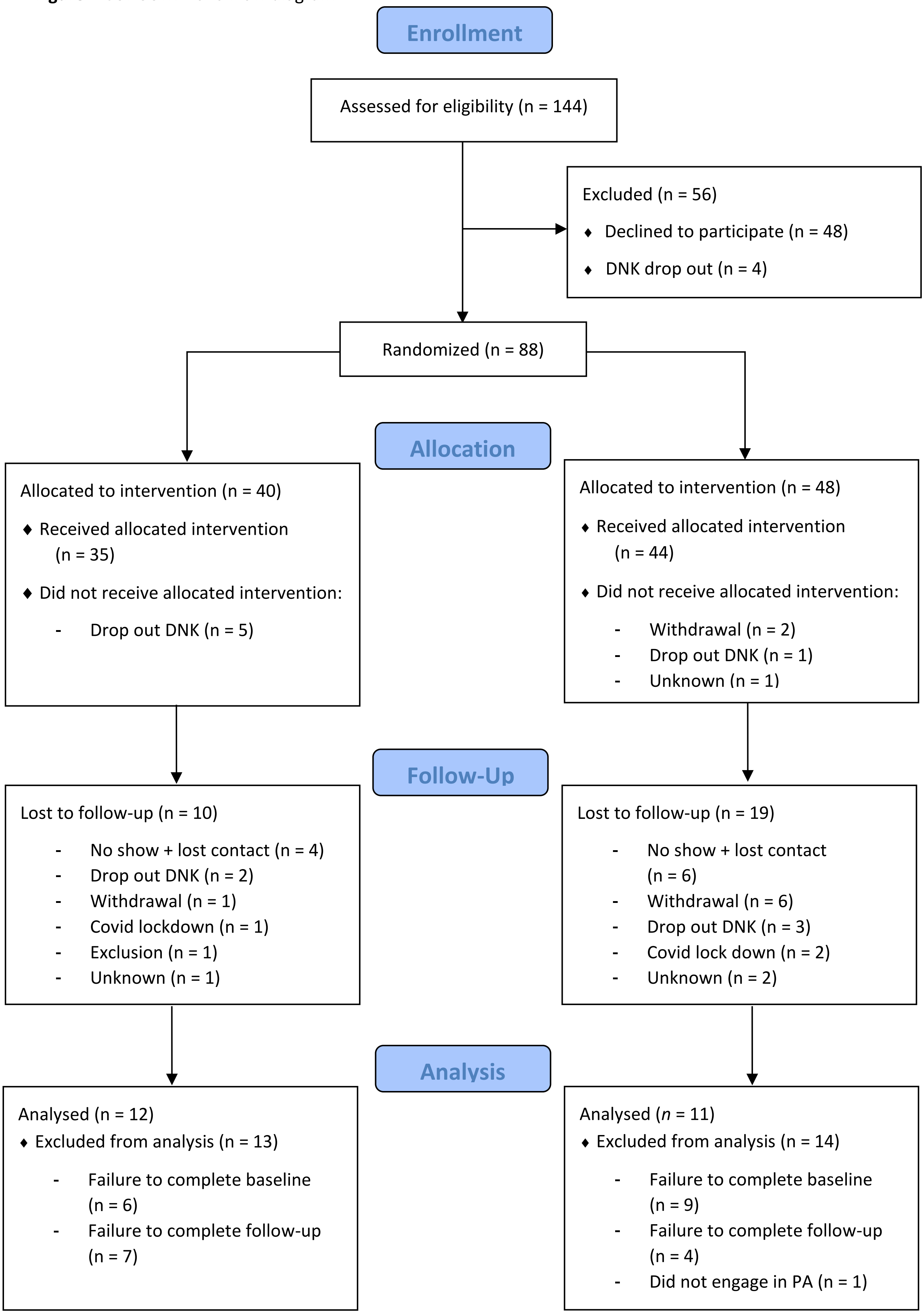
Participants were male multi-problem young adults (aged 18-27) recruited at the start of a multimodal day treatment program De Nieuwe Kans (DNK; translated as “New Opportunities”: for more information, see: (Luijks et al., 2017; Van der Sluys et al., 2020). There were 88 young adults randomized to the physical activity intervention, of which 48 completed baseline testing. Of those, 24 participants completed the follow-up six weeks later. One additional participant was excluded from the RCT-group analysis due to being judged by the coaches and researcher as being too inactive (did not participate in any of the activities) during the physical activity intervention. The final sample was therefore N = 23. See Figure 1 for the CONSORT flow diagram containing a description of exclusion reasons broken down per phase.

Common reasons to be lost post-treatment after randomization included failure to complete baseline testing within the first two weeks (n = 15), dropping out of the multimodal day treatment program during the intervention period (n = 11), failure to complete follow-up testing (n = 11), not responding to communication after setting an initial testing date (n = 10), and not wanting to continue with the intervention (n = 9). Other reasons were the Covid-19 lockdown (n = 3), not actively engaging during the physical activity intervention (n = 1), and having an insufficient understanding of the Dutch language (n = 1). Data on the reasons for non-response was lost for a small number of participants (n = 4).

Young adults at DNK suffer from a variety of problems, including lack of daytime activities (such as work and education), no income, no housing, behavioral and psychological problems, substance use, and a history of delinquency (Luijks et al., 2017; Zijlmans et al., 2020).

This treatment program is specifically designed for young male adults with several complex issues (e.g., behavioral, psychological, and financial problems; (Luijks et al., 2017; Van der Sluys et al., 2020)). The goal of the intervention is to aid the multi-problem young adults with their reintegration into society, by guiding them to education or employment and by increasing their self-sufficiency. To achieve this outcome, DNK applies a multidimensional approach including cognitive behavioral therapy, coaching, observation, and practical support. Participants are required to follow the treatment for 4 days a week (9.30 AM - 2.30 PM). On average, they need about 5 to 6 months to successfully obtain education or employment, thus ending the program. In some cases, the program ends with a referral to specialized (mental) health care, if this is deemed necessary and with the participants' consent.

Figure 1 CONSORT 2010 Flow diagram



Study design

The present study was an RCT design. Study participants were randomly allocated to either light-active physical activity lessons (e.g., table tennis, table soccer, walking; N = 12) or moderate-active physical activity lessons (e.g., weightlifting, fitness circuit, running; N = 11). Data was collected between October 2018 and March 2020 (first lockdown due to Covid-19). All participants received physical activity lessons twice a week lasting on average 1 hour per session as part of their compulsory day treatment at DNK. Due to practical and ethical constraints (such as the inability to withhold day treatment for a subsample of participants), it was not possible to examine the effect of physical activity without day treatment. Lessons for both groups were administered at the same time, but at different locations (e.g., the fitness room of DNK, outside, or the fitness center in the adjacent building). Two trained sports coaches, both staff members of DNK, delivered the lessons. The coaches were counterbalanced every 2 weeks to minimize any possible trainer effect on the RCT groups. No standardized fitness program was used as this was not possible with the current curriculum, but the coaches were given a list of light-active and moderate-active activities based on estimated intensity. Light-active activities included walking and cycling at a slow pace, ball games such as soccer, and recreational activities such as table tennis and table soccer. Moderate-active activities included running and cycling at a moderate pace, circuit training, and weightlifting with light cardio. A subgroup of the study participants was required to wear a Polar A360 activity tracker on their wrist during the physical activity lessons to measure heart rate.

The study has been approved by the Medical Ethical Committee of the VU University Medical Center (registration number 2013.422 - NL46906.029.13). Participants provided written informed consent. They received reimbursement of 20 euros for study participation (i.e., completing the computerized cognitive control tests and questionnaires at baseline and follow-up).

Procedure and study outcomes

All outcome variables were measured within two weeks of the start of the multimodal day treatment (baseline, median time between entry and testing = 8 days) and six weeks later (follow-up). Participants were eligible if they did not suffer from color blindness and had sufficient knowledge of the Dutch language. They were tested in their free time or at the end of the day when their mandatory classes and treatment at DNK were finished. All measurements were performed in one setting, in a quiet room at DNK. Laptops were used to administer the cognitive control experiments and the questionnaires.

Cognitive control

Cognitive control (indexed as response inhibition, error processing, and cognitive interference) was measured with three reaction-time experiments, using E-Prime 3.0 software (Psychology Software Tools Inc., 2016) and a QWERTY keyboard.

Response inhibition was measured with a Go/NoGo task (see (Luijten et al., 2013; Zijlmans et al., 2021) for more information). In short, participants were required to press the spacebar in response to a vowel (Go trials) and refrain from any response if the vowel was a repetition of the previously shown vowel (NoGo trials). Participants were shown a total of 927 trials of which 12% (110) were NoGo trials. Jitter was introduced in the number of intervening Go trials (M = 7.25, range 3-16). The experiment consisted of five blocks, divided by 15 sec rest periods.

The stimuli were presented at 1 HZ for a duration of 700 ms. This was followed by a blank screen (300 ms). The response window was set at 1000 ms (stimuli presentation + blank screen). NoGo accuracy was used as an index for response inhibition. Higher accuracy on NoGo trials is interpreted as better response inhibition.

Error processing was measured with a Flanker task previously described in Zijlmans et al (Zijlmans et al., 2019). To summarize, participants were shown letter strings (HHHHH, SSSSS, HHSHH, SSHSS). They were instructed to press the h or s, corresponding to the middle letter of the string. A total of 400 trials (200 congruent, 200 incongruent) were presented at random, divided into five blocks with 15 sec rests in between blocks. One trial consisted of 52 ms stimulus presentation, followed by 648 ms blank screen. Participants could respond during the stimulus presentation and the blank screen (i.e., response window set at 700 ms). The inter-stimulus interval was 1000 ms. 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 measures of error processing, with higher scores indicating better error processing.

Interference or Stroop effect was measured with a Stroop Color-Word task (see also: (Van der Sluys et al., 2022)). Participants were required to react to the color of the ink (red, blue, yellow, green) whilst ignoring the written words (red, blue, yellow, green). Color and words were congruent (48 trials) or incongruent (144 trials), presented in random order, and divided into two blocks. Participants reacted by pressing a letter (d, f, j, k) corresponding to the colored ink. The trial started with a fixation cross (250 ms), followed by the stimulus (shown until the participant pressed a letter, with a maximum stimulus presentation of 3000 ms). Interference effect (reaction time incongruent trials - reaction time congruent trials) was calculated as a measure of interference. A higher score is interpreted as increased (worse) cognitive interference.

Impulsivity and physical activity

Questionnaires were administered by trained researchers in the form of a structured interview using Castor EDC (Castor EDC, 2019). Trait impulsivity was added as an additional measure of inhibitory control (Leshem, 2016) because this related trait might also benefit from increased physical activity (Ghahramani et al., 2016). Impulsivity was measured with the Dutch Baratt Impulsiveness Scale (BIS-11; (Lijffijt, 2005; Patton et al., 1995)). Furthermore, we included a self-report measure of physical activity to control for individual differences in baseline physical activity level (Gomez-Pinilla & Hillman, 2013; Verburgh et al., 2014), as measured with the International Physical Activity Questionnaire long version (IPAQ: (Hagströmer et al., 2006)). Metabolic Equivalents (METs) minutes per week were used as a measure of physical activity level. To measure differences in intensity between the two groups, we measured heart rate during physical activity with Polar activity trackers. A weighted mean average was calculated for each group. Lastly, we conducted several questionnaires to describe the multi-problem character of the sample. These included a socio-demographic questionnaire, a screener for mild to borderline intellectual disabilities (SCIL 18+; (Nijman et al., 2018)), the Adult Self-Report (ASR: (Achenbach & Rescorla, 2003)), the Reactive Proactive Aggression Questionnaire (RPQ: (Cima et al., 2013; Raine et al., 2006)), and the WODC Self-reported Delinquency Questionnaire (Kruissink & Essers, 2004).

Adherence to the physical activity intervention

Adherence was defined as the percentage of completed sessions (i.e., actively engaging in the instructed light-active or moderate-active activities for at least 75% of the time of a single session) post-treatment. This was measured using daily lesson recording sheets completed by the coaches and the researchers.

Data analysis

All statistical analyses were conducted with IBM SPSS version 20.0 (2011). Pre-intervention group differences were measured with multivariate analyses of covariance (MANCOVA) on baseline data (start of treatment) of the selected indices of cognitive control (i.e., NoGo accuracy, Flanker total accuracy, Flanker post-error slowing, Flanker correctness effect, Stroop interference) and trait impulsivity (i.e., BIS-11 total score), controlling for physical activity level (i.e., MET minutes per week). Furthermore, a repeated measures (RM) MANCOVA was used to examine any differences between the light-active and moderate-active group (between-subjects factor) with time (baseline to post-treatment 6 weeks later) as within-subjects factor, controlling for baseline MET minutes per week. Level of significance was set at p = .05.

Results

Participants were between 18 and 27 of age (M = 21.1, SD = 2.7). Nineteen percent had a Western ethnicity (i.e., Dutch or Belgian). The remaining 81% had a Dutch Antilles (28.6%), Moroccan (15.9%), Surinamese (7.9), African (7.9%), Cape Verdean (4.8%), Syrian (3.2%), or another non-Western (11.1%) ethnic background. Information on ethnicity was missing for one participant. See Table 1 for a detailed description of sample characteristics.

The weighted average heart rate during physical activity was 112.28 beats per minute in the light group and 115.96 beats per minute in the moderate group 115.96. An independent sample t-test revealed the difference was not significant (M_{diff} = -3.70, p = .134). Because of this and the relatively small sample size per group (N_{light} = 12 and $N_{moderate}$ = 11), we decided to also report the main effect of group in the RM MANCOVA, to examine if there were any treatment effects in the complete sample.

Effect of six weeks physical activity

The MANCOVA on baseline data (N = 48) did not show any significant pre-intervention group differences in cognitive control and trait impulsivity, after controlling for MET minutes per week (F (6, 40) = 0.567, p = .754; Wilk's Λ = .922, partial η^2 = .078), indicating successful randomization.

After controlling for baseline MET minutes per week, results from the RM MANCOVA (N_{light} = 12 and $N_{moderate}$ = 11) revealed a significant main effect of time on cognitive control (F (6, 15) = 2.820, p = .048; Wilk's Λ = 0.470; partial η^2 = .530). More specifically, when looking at the individual variables, we found increased NoGo accuracy (p = .037), increased total Flanker accuracy (p = .031), and decreased Stroop interference effect (p = .003).). See also Table 2 for an overview of mean scores at baseline and after six weeks. There was no significant main effect of group (F (6, 15) = 2.820, p = .048; Wilk's Λ = 0.470; partial η^2 = .530), i.e., the treatment effect was not significantly different between the two groups. The time by group interaction was also not significant (F (6, 15) = 0.838, p = .560; Wilk's Λ = 0.749; partial η^2 = .251). These results indicate that overall, there was an improvement in NoGo accuracy, total Flanker accuracy, and Stroop interference from pre- to post-treatment, however, the effect of treatment did not differ between the light-active and moderate active group, possibly because the difference in intensity was not significant.

Table 1 Descriptives (N = 63)

Variable	*M (SD) / %*
Age	21.1 (2.7)
BMI	23.1 (4.2)
Highest finished education	
No education	11.5%
Primary education	19.2%
Secondary education	69.2%
SCIL score (<19) indicative of possible intellectual disabilities	88.5%
Western ethnicity (i.e., Dutch and Belgian)	15.4%
Non-Western ethnicity (e.g. Dutch Antilles, Moroccan, Surinamese, African, and other)	84.6%
Family problems in youth – self-report	
No problems	38.1%
One parent (mostly) absent	20.6%
Mental health problems of family members	4.8%
Domestic violence	14.3%
Police contact of family members	27.0%
Drug use of family members	12.7%
Alcohol use of family members	12.7%
Daytime activities	
No daytime activities	61.3%
Work	19.9%
Education	5.0%
Caring for others	3.3%
Sport	6.4%
Other (e.g., volunteering, treatment)	4.1%
ASR internal problems	61.1 (11.1)
ASR external problems	59.8 (9.8)
RPQ reactive aggression	3.1 (2.1)
RPQ proactive aggression	4.9 (3.3)
Cannabis use past 30 days (units)	13.1 (13.7, range 0-30)
Alcohol use past 30 days (units)	2.6 (6.1, range 0-29)
Years of regular cannabis use (i.e., weekly use)	3.3 (3.3, range 0-11)
Years of regular alcohol use (i.e., weekly use)	1.3 (2.9, range 0-11)
Self-reported delinquency	
Destruction/public order offence - lifetime	54.0%
Property offence - lifetime	74.6%
Aggression/violent offence - lifetime	60.3%
Weapon offence - lifetime	39.7%
Drug offence - lifetime	57.1%

Note. SCIL = Screener for Intelligence and Learning Disabilities; ASR = Adult Self Report; RPQ = Reactive Proactive Questionnaire; BMI = Body Mass Index

Table 2 Descriptives of main outcome measures over time (N = 23)

	T0 (baseline)	T1 (follow-up)
	M (SD)	*M (SD)*
Stroop interference (RT incongruent - RT congruent) **	70.7 (54.0)	29.3 (32.8)
Flanker total accuracy *	0.82 (0.15)	0.86 (0.14)
Flanker post-error slowing	25.9 (35.4)	15.8 (32.2)
Flanker correctness effect (RT correct - RT incorrect)	-31.9 (64.1)	-31.2 (66.0)
NoGo accuracy *	0.54 (0.1)	0.59 (0.2)
BIS-11 impulsivity total	68.1 (8.5)	65.3 (9.2)
IPAQ METs	4377.52 (954.9)	n/a

Note. BIS-11 = Barratt Impulsiveness Scale; CI = Confidence Interval; IPAQ = International Physical Activity Questionnaire; METs = Metabolic Equivalent minutes per week; RT = reaction time; T0 = start of multimodal day treatment; T1 = 6 weeks later

Adherence to the physical activity intervention

The median intervention adherence from baseline to end of the 6-week intervention was 33% in the group of randomized participants (N = 88). Twenty-nine percent of the participants completed at least half (i.e., 6 or more) of the prescribed physical activity lessons, 62% completed 5 or fewer sessions, and 9% did not attend any of the sessions. Excluding participants who dropped out of the multimodal day treatment program (and thus could not continue with the physical activity intervention) did not increase the median adherence. An independent sample t-test showed no difference in adherence rates between the light-active and moderate-active group.

Discussion

The current study investigated whether six weeks of light-active versus moderate-active physical activity embedded in a multimodal day treatment program would improve cognitive control (i.e., response inhibition, error processing, and cognitive interference) and trait impulsivity in multi-problem young adults. We could not confirm our hypothesis, as the moderate-active group did not show more improvement in executive functioning and trait impulsivity after six weeks of physical activity compared to the light-active group. However, both groups demonstrated enhanced cognitive control post-treatment, specifically improved inhibition, improved performance on an error-processing task, and improved (i.e., lower) cognitive interference, indicating physical activity might be a viable option to enhance various neurocognitive functions. No improvement was found on trait impulsivity. It is possible that the current intervention was too short to elicit any changes as prior research suggests a persistent intervention of at least 18 months is needed to alter personality traits (Bleidorn et al., 2019). To the author's knowledge, this study is the first to examine the effect of a physical activity intervention on cognitive control in young adults with multiple problems including aggression, substance use, and a history of delinquency. As we did not observe a significant difference in heart rate between the two physical activity groups, it is possible that the current activities (e.g., table tennis, table soccer, walking, vs. weightlifting, fitness circuit, running) were too similar in terms of intensity to elicit any differences in treatment effect (Kaiser et al., 2022), and more research is needed to establish if there is a dose-response association. Despite the non-significant effect of intensity, our findings are consistent with the limited existing intervention studies in healthy adolescents and young adults.

Prior research in healthy younger adults (*M* age 22, range 17-47) revealed positive exercise-induced effects on cognitive interference compared to no-exercise controls after 17 weeks of running (Stroth et al., 2010). This is further supported by a study where 8 weeks of aerobic and coordinative exercise during school days resulted in enhanced cognitive interference in adolescents (aged 12-15) compared to an attention-only control group (Ludyga et al., 2018). Another study found that 9 weeks of moderate aerobic exercise significantly enhanced error processing (i.e., faster reaction times on the Flanker task) in healthy young adults (aged 18-20) compared to waitlist controls (Zhu et al., 2021). These beneficial effects may be due to increased cerebral oxygenation (Goenarjo et al., 2020), increased cortical thickness in the frontal lobe, and increased frontal gray matter volume (Stern et al., 2019). Such neurobiological changes may become more prominent with age (Stern et al., 2019), suggesting larger effects in older adults. The lack of literature on young adults complicates any definite statements. However, together with the promising findings in healthy children and older adults (Alvarez-Bueno & Pesce, 2017; Chen et al., 2020; Liu et al., 2020), the current results suggest physical activity interventions may exert a positive influence on (some) cognitive functions throughout the lifespan.

The present study is not without limitations, with the most prominent being the fact that the physical activity intervention was embedded in a multimodal day treatment program (i.e., practical guidance, lessons including culture, cooking, and cognitive behavioral therapy (Luijks et al., 2017)). Caution is thus advised interpreting current results, as it is not possible to completely discern any possible effects of the multimodal treatment from the physical activity intervention. Although this complicates any causal statements about the isolated effect of physical activity, it also contributes to our understanding of an ecologically valid sample of treatment-seeking young adults with complex and co-morbid problems. To the best of our knowledge, no studies have been conducted on the effects of similar multimodal treatments on cognition. However, related studies on the efficacy of cognitive behavioral therapy (i.e., one of the main components of the multimodal treatment) did not uncover a significant effect on cognitive control in adults with obsessive-compulsive disorder (Vandborg et al., 2015) or attention deficit disorder (Virta, 2010), suggesting this may also be the case for our multi-problem sample. Other effective approaches to increase neurocognitive functioning include mindfulness (Larson et al., 2013) which is not a part of the current treatment curriculum. In contrast, physical activity has been known to improve cognitive control in younger adults (Stern et al., 2019), suggesting physical activity may have (at least partially) contributed to the positive effect on cognitive interference.

It is also important to discuss the relatively low number of participants who completed the follow-up testing (27% of the young adults who were initially randomized). We used small financial incentives (5 euros for making the appointment and 5 euros for completing the tests) and reminders to encourage participants to complete both baseline and follow-up testing (Booker et al., 2011). In addition, we collected multiple sources of contact information (Stewart et al., 2021) and tried to accommodate the young adults as much as possible regarding the time and place of the testing. Other types of incentives or more frequent contact to stimulate bonding (Booker et al., 2011) may be more effective to maximize retention. Regardless, it is not uncommon for effect studies with similar hard-to-reach or at-risk populations to have small sample sizes ranging between 10 and 20 participants (e.g., see (Lubans et al., 2012; Sanchez-Lastra et al., 2019)), for example, due to frequent changing or lack of address and phone numbers, starting a new day treatment and not having enough time, and having physical and mental health problems (Fahmy et al., 2022).

Last, although the physical activity lessons were mandatory for all young adults starting the multimodal day treatment (independent of study participation), we observed a relatively low adherence (i.e., only 29% attended at least half of the lessons), indicating low compliance and/or enforcement of the compulsory nature. Although we did not question participants about their reasons for (not) participating, we observed a general lack of motivation to exercise in most treatment seekers during the multimodal day treatment (independent of study participation or allocation). Including only participants who are willing to exercise may increase adherence, yet it would also introduce bias. Another option is to increase motivation, for example through gamification (Kari et al., 2016) or physical performance goals (Gorny et al., 2021). Low adherence is a continuing problem in physical activity RCTs (Eldridge et al., 2016; Slade et al., 2016) and further research should be undertaken to investigate factors associated with low adherence, such as personality (Lewis & Sutton, 2011).

In sum, in spite of its limitations, these results suggest that engaging in physical activity for six weeks may benefit cognitive control in multi-problem young adults, even at light intensity. As physical activity is relatively inexpensive and easy to implement, it may serve as an alternative or additional intervention for treating cognitive control deficits, yet more research is needed to increase the number of participants completing the follow-up testing and adherence to the physical activity intervention.

CHAPTER 7

Using physical activity to support multi-problem young adults during emerging adulthood: a thematic analysis

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In preparation

Abstract

Previous research indicates that physical activity may be used to support young adults during their transition into healthy adulthood, yet this has not been studied in multi-problem young adults. This study interviewed 15 young adults suffering from a range of (financial, behavioral, psychological, and judicial) problems about the role of physical activity in their lives, and how it could be used to support and aid these young adults. The perspectives of four key witnesses (i.e., sports coaches and social workers) were used to supplement these results. Using a thematic approach, we discovered four themes. First, physical activity can serve as an outlet for stress and emotions. Second, it can stimulate personal development, including a decrease in externalizing behavior. Third, we identified several aspects (e.g., supportive climate, motivation, willingness) related to positive outcomes. Lastly, within all these themes, the crucial role of the sports coach became apparent. In sum, the current results indicate several ways in which physical activity can aid multi-problem young adults during emerging adulthood, emphasizing the importance of creating a safe environment with a competent and identifiable coach.

Introduction

The transition from late adolescence into young adulthood (aged 18-28) is a turbulent period characterized by identity development (Schwartz et al., 2013), increased independence (Arnett et al., 2014), and several psychological, societal, and neurobiological changes (Alessandri et al., 2016; Arnett, 2007; Nelson & Barry, 2005; Parra et al., 2015). This phase, also called emerging adulthood, can be especially challenging for vulnerable young people, such as multi-problem young adults, lacking sufficient resilience and resources (Osgood et al., 2010). They are mostly unable to navigate into healthy adulthood (Anda et al., 2006; Arnett, 2007; van Duin et al., 2018) and their transition is marked by an accumulation of problems, including no daytime activities (i.e., no work, education, or other fulltime day activities), no or low income, a history of delinquency, substance (ab)use, and internalizing and externalizing problems (Van der Sluys et al., 2020; Zijlmans et al., 2020). Their problems can originate from environmental (e.g., negative experiences with family, peers, and society), material (e.g., lack of resources including education), emotional (e.g., lack of support, care, and love), and social (e.g., lack of role models and a supportive peer group, delinquency of friends) factors (Arora et al., 2015). Physical activity including exercise and sports might aid these multi-problem young adults with their transition into adulthood, by generating positive meaningful experiences in most or all of these areas (Donaldson & Ronan, 2006; Haudenhuyse et al., 2013; Haugen, 2011.; Liu et al., 2015; Perkins, 2010; Ruseski et al., 2014).

However, existing physical activity research focuses predominantly on youth (aged < 18) from the general population (Eime et al., 2013; Opstoel et al., 2019). In youth, researchers and policymakers are increasingly advocating physical activity as a tool to stimulate healthy behavior (Bichel et al., 2010), increase mental well-being (Donaldson & Ronan, 2006; Ruseski et al., 2014), and promote positive youth development (Lumpkin, 2011; Makkai et al., 2003; Sandford et al., 2006). More specifically, it can provide them with meaningful experiences such as feelings of support (Haudenhuyse et al., 2013) and social inclusion (Perkins, 2010). In addition, the physical activity or sports setting can be used to develop and improve important abilities and values (i.e., life skills (Danish et al., 2011)) such as self-esteem and self-worth (Haugen, 2011; Liu et al., 2015), self-regulatory skills (Howard et al., 2018), and prosocial behavior (e.g., sportsmanship and respect (Kumar, 2017; Lumpkin, 2011; Nucci et al., 2005)). Lastly, it may strengthen coping abilities (Holt, 2007), building resilience to better deal with the demanding requirements of emerging adulthood. Taken together, these studies indicate the potential of physical activity to not only increase positive but also decrease negative behavior.

Yet, despite the increased political interest in physical activity programs to rehabilitate and support antisocial and delinquent youth (Sandford et al., 2006; Sandford et al., 2008; Welland et al., 2020), there remains a paucity of evidence as existing research is scarce and inconclusive (Hermens et al., 2017; Lubans et al., 2012; Super et al., 2018). Results from quantitative studies indicate that not all young individuals are benefitting equally from physical activity (Corazza et al., 2019; Duncan et al., 2002; Howie et al., 2016; Kelly, 2013) and some youth even experience detrimental effects including reduced self-esteem (Andrews & Andrews, 2003), increased feelings of social exclusion (Sun & Shen, 2007), and declined mental health following failure or overtraining (Brenner et al., 2007). Previous literature suggests that not the act of participating, but rather the subjective experience of participating is important in the facilitation of positive outcomes such as personal development (Coakley, 2011; Opstoel et al., 2019; Papacharisis et al., 2005). In other words, to better understand when and how physical activity can be used to support young people suffering from several problems, more information is needed on their personal experiences, attitudes, and beliefs surrounding physical activity (Coalter, 2017). So far, however, very little is known about the experiences of multi-problem young adults, as existing qualitative literature is primarily focused on youth (aged < 22) with a heightened susceptibility to negative events including abuse and delinquency (i.e., vulnerable youth: (Haudenhuyse et al., 2013; Osgood et al., 2010; Super et al., 2017a)). Although these groups are somewhat comparable, the difference is that vulnerable youth are at-risk to manifest several problems, whereas multi-problem young adults are already suffering from a plethora of these problems.

To date, only one qualitative study examined the experience of vulnerable emerging young adults (aged 21-31), yet rather than asking them about their current sports experiences, they were asked to reflect on the role of sports in their (socially) vulnerable childhood (Super et al., 2017b). The young adults considered sports in their childhood as an instrument (i.e., to reach specific goals or to become part of their identity), as a learning environment, and as a place to escape their daily struggles. Negative experiences (e.g., bullying, overtraining) were also mentioned. In another study in vulnerable youth (aged 10-18), the same authors uncovered a delicate balance between positive and negative sports-club experiences (such as group pressure and anger) related to three themes (e.g., visibility of skills, confidence during sports, and the feeling that sports was a challenge they wanted to take on (Super et al., 2017a)). More importantly, the sports coach was often mentioned as a key-player in tipping the balance towards more positive experiences. This is in line with another study on sports-club experiences in vulnerable youth (aged 10-22), where the sports club setting could be a supportive and safe environment, but only if the coach and sports club actively pursued such a climate (Haudenhuyse et al., 2013). Lastly, from the accounts of participants of a boxing initiative for vulnerable youth (aged 12-18), it became apparent that the identity of the coach was also important (Haudenhuyse et al., 2012), as it was easier for the youngsters to connect and learn from a coach they could identify with, for example by sharing a cultural or otherwise similar background.

Although these studies provide us with relevant insights into vulnerable young people, the question remains how young adults suffering from multiple problems during their transition to adulthood reflect on the meaning of physical activity in their daily life. Previous research including a large sample of multi-problem young adults (recruited at the same site as the current study) indicated moderate to severe problems in multiple life domains (i.e., justice, addiction, social, and mental health) including high self-reported delinquency, high cannabis and alcohol usage past 30 days, high friends' delinquency rates, and high internalizing and externalizing problems (Zijlmans et al., 2020). In addition, these young adults showed a high prevalence of childhood risk factors including adverse childhood experiences, service use, and residential mobility) (van Duin et al., 2017, 2018; Zijlmans et al., 2020).

Prior research, although limited, suggests that the physical activity setting may provide opportunities to support these young adults with their problems and to aid them with the transition into adulthood. However, information on the experiences of young adults is lacking and it is not self-evident that all experiences are positive. Moreover, possible negative experiences (e.g. bullying, overtraining, group pressure) may exacerbate their problems. Given the scarcity of research on this topic, the current study therefore aims to examine the perspective of multi-problem young adults on physical activity (e.g., sports and exercise) as a tool to aid them with their problems. We are particularly interested in the experiences of young adults pertaining to physical activity, the role it plays in their lives, and what is needed to better support them through physical activity. The perspectives of four key witnesses (i.e., sports coaches and social workers) will be used to supplement these results.

Methods

Procedure and participants

A qualitative design was employed using semi-structured interviews, lasting on average 63 minutes. The use of a topic guide (Table S1 in supplement) provided loose structure, simultaneously allowing the participant to elaborate on important or relevant other experiences (Fontana & Frey, 2000). Convenience sampling based on willingness and proximity was used. Participants were contacted by phone, e-mail, or social media such as Facebook or Instagram and asked if they would be willing to participate in the interviews. All interviews were conducted online via video conference apps (e.g., Zoom, Teams) or by telephone. Only audio was recorded, using a digital voice recorder. In total, we conducted interviews with 15 multi-problem young adults. Two male sports coaches and two female social workers also agreed to be interviewed as key witnesses to increase data validity (Carter et al., 2014).

All multi-problem young adults were male, ranging in age from 19 to 27 years (*M* 23, *SD* 2.5). During the RCT data collection, they were enrolled in a multimodal day treatment at *De Nieuwe Kans* (DNK; translated as “New Opportunities”) specifically designed to treat young adult men (aged 18-27) suffering from a range of problems including financial, behavioral, and psychological problems (Luijks et al., 2017; Zijlmans et al., 2020). By applying a multimodal approach including cognitive behavioral techniques and practical support, DNK aims to reintegrate participants back into society by providing them with education and employment (Luijks et al., 2017). None of the young adults received treatment at DNK at the time of the interviews (median time since last DNK-treatment = 23 months, range 14 - 27 months). All key witnesses were (currently or previously) working at DNK.

We assessed several environmental, emotional, and social characteristics in the young adult sample. Fourteen of the 15 participants had a non-Western migration background, such as a Moroccan or Dutch-Antillean ethnicity. The interviewed young adults mostly did not have a fulltime daytime activity (e.g., employment or education). Thirteen percent did not have any education and 33.3 percent only finished primary education. The remaining young adults finished secondary pre-vocational (20%), secondary senior education (13.3%), or secondary vocational education (20.1%). They spoke of precarious childhood situations, having been exposed to adverse childhood experiences such as parental substance ab(use), domestic violence, and parental mental health disorders. Moreover, seven of the interviewees were in treatment for psychological problems (e.g., past trauma, post-traumatic stress disorder, autism). Three reported having been to prison in the past, and two were currently under supervision of a probation officer.

Ethical approval was granted by the Scientific and Ethical Review Board of the VU University Amsterdam (VCWE-2017-139). Participants were informed about the interview procedure and the ethical guidelines, as well as the possibility to refrain from involvement at all times (passive informed consent). They received a reimbursement of 10 euros. Pseudonyms (taking ethnic origin into account) were used to describe the participants.

Data collection strategy

The interview guide was developed by the researchers based on previous studies (Haudenhuyse et al., 2013; Super et al., 2017b, 2017a) and pre-specified interests. After a short introduction, the interview started with background questions related to daytime activities, current physical activity (e.g., sports and exercise), and motivation for (not) engaging in physical activity. The following part covered several topics related to physical activity (e.g., sports and exercise) such as their positive and negative experiences, the meaning and value of physical activity, how they best felt supported through it, and how it could be used as a tool to aid with their problems. The interview ended with three questionnaires to describe the sample and assess the multi-problem character of this group. These included a socio-demographic questionnaire, the International Physical Activity Questionnaire (IPAQ: (Hagströmer et al., 2006)) to measure self-reported physical activity level (i.e., high, moderate, or low), and the WODC Self-Reported Delinquency (WODC questionnaire; (van der Laan & Blom, 2006)) to measure self-reported delinquency. The topics for the sports coaches and social workers focused on what they considered to be the role of physical activity in the multi-problem young adult' lives, and how we could better support these young adults with physical activity according to their experiences.

Data analysis

All interviews were recorded using a digital voice recorder. They were transcribed verbatim and anonymized. A thematic approach was used to analyze the data, as this systematic approach allows the identification and subsequent interpretation of patterns of meaning (i.e., themes) in the data (Braun & Clarke, 2006). The thematic analysis was conducted following the method specified by Braun and Clarke: obtaining familiarity with the data by (re)-reading the transcripts; generating initial codes; reviewing the codes to identify themes; reviewing the themes for internal homogeneity and external heterogeneity; and defining and naming the themes (Braun & Clarke, 2006). To reduce risk of bias, the second reader (EG) independently coded a selection of interviews. The codes were then compared, and any discrepancies were discussed until agreement was reached. The first author (MS) used the final codes to form the themes, which were again discussed with the second reader (EG). Transcripts were coded using MXQDA 2020 Version 20.1 (Verbi Software, 2019).

Results

Physical activity

All participants actively engaged in multiple forms of physical activity (e.g. sports and exercise) during their life course. Four young adults were currently not participating in physical activity, yet all had plans to start in the near future. Participants were currently engaged in soccer (n = 6), weight training (n = 5), walking/running (n = 4), baseball/softball (n = 2), martial arts (n = 1), or basketball (n = 1). In the past, most young adults participated in martial arts (n = 7), followed by soccer (n = 6), swimming (n = 4), weight training (n = 2), baseball/softball (n = 1), basketball (n = 1), turning (n = 1), tennis (n = 1), and hockey (n = 1). For an overview of types of physical activity specified per individual, see Table S2 in supplement.

Themes

Most participants shared positive sports-related experiences, as physical activity overall impacted their mood and life positively. However, they also mentioned how sports and exercise does not fix everything and how it can only help to a certain degree. Negative experiences (related to the second theme) are also discussed. Four themes emerged from the data: physical activity can serve as an outlet and it can stimulate positive personal development, yet to do so, several prerequisites need to be met. Lastly, the importance of the sports coach in all these themes is emphasized. Table 1 provides a summary of the themes and associated categories.

Table 1 Summary of themes and categories

Theme	Category
PA can serve as an outlet	Clears mind
	Reduces stress
	Calms mind in possible aggravating situations
	Reduces excess energy
PA can stimulate personal development	Regularity and structure
	Social skills (e.g., discipline, respect, cooperation)
	Coping skills (e.g., confidence, perseverance, resilience)
	Reduced externalizing behavior (e.g., aggression, delinquency, substance use)
	Can also have negative effects (e.g., increased aggression)
Prerequisites of PA to better support young adults	Willingness
	Right headspace
	Motivation, determination, perseverance
	Resources (e.g., time, money, knowledge)
Importance of having a competent and identifiable coach	Coach can aid with several barriers (e.g., motivation, headspace, knowledge)
	PA can be used to learn about behavior (coach + social worker)
	Safe environment important
	Coach has to be identifiable

Note. PA = physical activity

Theme 1: Physical activity can serve as an outlet

The first emerging theme related to physical activity as an outlet. When asked about the meaning of physical activity, the young adults first and foremost mentioned how physical activity served as an 'outlet', used to 'clear your head, just thinking about nothing'. This provided them with an escape from their daily struggles, helping them to (briefly) forget their problems or divert their attention. Sports and exercise could also be used to actively alleviate stress, for example Carlos (running, weight training) says:

> *Especially when I'm at home stressing or worrying, then I'll just go for a walk outside or a run. That helps me when I return. So yes, then I'm not as stressed as before.*

In this regard, it is interesting to note that the majority of the interviewees were not only aware of the stress-relieving properties of sports and exercise but that they actively engaged in physical activity to reduce their stress. This indicates that the multi-problem young adults were able to recognize potential stressful situations and to proactively prevent further escalation. This is illustrated by Lorenzo (fitness), who discusses how he 'really needs to exercise' in situations where his stress is rising, as 'it [exercise] just really calms me down'. This calming effect has been explicitly mentioned by multiple other interviewees, such as Michael (walking), who states that 'for me, sports is very important, especially to unwind, [so] that I can release my energy'. Feeling calmer and more relaxed helped these young adults to think more clearly, which in turn could result in more balanced decisions. As this participant summarizes:

> *I guarantee you, put on some punching gloves and punch a boxing bag a couple of times, yeah you might be like [panting], like angry, but after a while you're like, man wow, I feel so relieved, like I let go so much, you know? So sports really play a role in your stress level.*

Theme 2: Physical activity can stimulate positive personal development

The second theme related to the stimulation of personal development. Most participants stated that physical activity contributed to the development of life skills (i.e., important abilities and values needed for a balanced and proactive life (Danish et al., 2011)). The routine of a work-out and the consistency of training throughout the week provided them with structure and regularity, which they often lacked in other life domains. This had a positive spill-over effect on other parts of their life, resulting in healthier habits such as quitting smoking, eating regular meals, and going to bed early. As Reda (weight training) explained:

> *For example, you have to go to bed on time if you know that you are going to work out in the morning. So that's how you get a certain routine in your life… If you immerse yourself in sports, then you also know that [getting] enough sleep is necessary to achieve your goals with sports, so then you don't behave like a teenager [and] sleep four hours a day or less, you know?*

Furthermore, exercising in a team or with others could stimulate the development of several social life skills, such as discipline and respect. Other participants reported learning listening, motivating, and helping others, and cooperating.

Lastly, regarding personal development, the majority of young adults also spoke of life skills that could help them cope with their daily struggles, such as confidence, perseverance, and resilience. Ahmed (no current physical activity, but plans to start soccer again) mentioned how working out gave him more confidence, confirming that he felt like 'yes, I can do that' when he mastered specific exercises and Lorenzo (fitness) regained his self-esteem through physical activity, after struggling with low self-confidence for a long time.

The relevance of physical activity in developing and supporting life skills was also present in the accounts of the key witnesses. One key witness expressed how he thought that 'the things you can get out of exercise have an impact on your general well-being. So how you stand in life and how you deal with things.' This was supported by another key witness, who makes the comparison between perceived problems in the sports setting and perceived problems in daily life, and how mentality and willpower can be strengthened in the gym.

Using the sports setting as a learning environment did not only increase positive behavior of the participants, but could also decrease negative behavior such as aggression, delinquency, and substance use. This could be by mimicking aggravating situations in the sports setting, teaching them self-control and patience, or by teaching them other strategies to stay calm, such as adapting a 'general more positive mindset'. Some stated that physical activity could also be used to create a diversion from externalizing behavior, for example by going for a run when they were experiencing feelings of aggression or anger. In addition, physical activity offered these young adults something positive to focus on, helping them to further prevent or reduce criminal behavior. Carlos (running, weight training) describes how soccer helped him to divert from delinquency, as his friends would use their leisure time after school to steal stuff in the city, whereas he 'was just playing soccer'. Derrick (soccer) reflects on a similar experience in which joining a sports club led to the formation of new friendships and his distancing from old friends who used to 'hang out on the street'. Four other participants also mentioned how sports specifically helped them to create a distance between them and criminal behavior. As John (basketball, soccer) explains:

> *Sports mean a lot to me in the sense that they have helped me during times when I was experiencing difficulties such as hanging out with bad guys and et cetera. Sports helped me avoid going out on the streets and always kept me focused on the goals I had to achieve in life. So, that's important. Sports have played a very big role in that part of my life.*

The importance of sports and exercise in preventing negative behavior is also illustrated by Faiz (soccer, running, boxing), who describes how when he grew up, a lot of boys used to play soccer on a square nearby and how this helped him to stay on the right path:

> *I really noticed that as long as I had that ball with me, it was positive. Why? It kept me from [doing] negative things, you know? … It [the ball] was kind of a friend really… It is just a ball but still, that one ball, it caused a lot of good things, because I felt like playing soccer and I did not feel like doing bad things, you know?*

A few participants even mentioned a positive effect of exercising on cannabis use, stating how they are craving less for a joint when they are working out. This is amended by the personal experience of one of the key witnesses, who used to be addicted to hard drugs yet used sports to work on himself positively which ultimately helped him to stay clean.

A small number of interviewees suggested that physical activity could also have negative effects, for example if it resulted in ignoring the root of the problems or when the search for a diversion resulted in obsessive training. For a minority, physical activity even increased their externalizing behavior. One participant stated how fitness 'made him aggressive' and another had to quit kickboxing because 'It just made me mad, if you punch me in the face or something or if you hit me in the face, I can become very angry, aggressive. So that’s why I quit.' From this perspective, the young adult was not only able to recognize his triggers (getting punched in the face) but also to act consequently (quitting kickboxing). The possible negative effects of physical activity and the fact that the young adults mostly recognize their triggers are also referred to by a key witness, who states:

> *Well, I also know of some [participants], who have aggression problems, that they were extra triggered by certain types of sports, and that they were even more excited than they already were. And luckily they were often able to tell that, but that is really an opposite effect of what you would want of course.*

Specifically, she mentions how boxing and kickboxing are problematic for those young adults, as they may increase anger. She later on continues explaining other ways in which physical activity could trigger negative outcomes, such as when young adults who suffered assault have to have close physical contact during some sports, or when the high-pitched tone of a whistle may trigger the Post Traumatic Stress Disorder in some participants.

Theme 3: Prerequisites of physical activity to better support young adults

The third theme was labeled prerequisites. When asked about what these young adults needed to feel better supported through physical activity, both the multi-problem young adults and the key witnesses were almost unanimous in the view that willingness (to exercise, but also willingness to change or to deal with your problems) was the most prominent factor. More specifically, as one young adult observed:

> *Because there are also people who are still unhappy while they're exercising, so… exercising isn't a miracle cure making you suddenly happy. You'll have to take control of your own happiness, you know?*

Other participants amended to this, including Michael (walking), suggesting that it isn't enough for others to tell you what to do, but that you 'have to, again, be willing to take on the extra, the exercise, the practice.'

According to the key witnesses, the willingness to change was closely related to having the right headspace. While physical activity can sometimes help clear the minds of young adults and relieve stress, there were instances where their negative mental state acted as a barrier to engaging in and benefiting from physical activity. One key witness states how the young adults sometimes mentioned having a 'hot head' from all their problems, meaning 'that they have too many things on their minds to focus on sports or enjoy working out at all'. This is supported by another key witness, explaining:

> *And some guys, you know, they could really use it [physical activity], but they're so full and stuck with the stress, that they just don't have the [mental] space to start something new again. So maybe sports would be something very- It would be very helpful, but then sometimes [it is] something that they just don't have [the] room for.*

Three other important resources included motivation to start, determination to keep going, and perseverance to continue despite hardships. Wilder (soccer) recognized how he needed the right headspace for these skills, confirming the prior statement of the key witnesses, saying how you need 'motivation and perseverance', which he lacked because his 'head was more [occupied] with other things'.

Most other participants recognized the benefits they could gain from physical exercise, but they often struggled to find the motivation and determination. Caleb (no current physical activity, but plans to start with fitness) says how he likes to exercise, but finds 'it hard to get started'. Michael (walking) states how motivation and determination 'depend on the type of person you are and the mindset you have, and what you want to achieve'. This is also illustrated in the account of Lorenzo (fitness) who lost his exercise motivation, but regained this after setting a specific goal (seeing result).

Not having certain resources was sometimes mentioned as a barrier, preventing young adults from exercising. These included practical resources such as time, opportunity, and money, but also the knowledge to work out without injuries (which was mostly related to working out with weights).

Theme 4: The importance of having a competent and identifiable coach

Lastly, in all of the abovementioned themes, the role of the coach or trainer was mentioned as an important factor. Having a competent coach could help these young adults with their barriers, for example by encouraging them or providing them with a listening ear or sports-related advice. More importantly, the sports setting could be used by trainers and coaches to stimulate positive behavior and discuss negative behavior. One key witness describes how physical activity can be used to 'observe what kind of person [somebody is], or which personality traits they show'. This key witness then continues how this could be used to start a conversation about how these traits translate into the young adults' daily life. This is reiterated by another key witness:

> *But when it comes to behavior, yes then you can use sports to emphasize that and make them aware that it's not just about hitting the ball or winning or because they lost. That it's all a part of [it]… And that also comes back in normal life. So that's how you make that link or that translation… with reality.*

Some participants mentioned how the sports setting offered them a safe place where they could 'find a new family' or process emotional traumas. One participant used the sports setting as a place where he 'could be himself', escaping an 'unsafe situation at home'. The best friend of Lorenzo was stabbed to death almost a year ago, and this participant describes how he has trouble processing this situation and letting go. Working out (fitness) gave him a purpose, saying 'that's [his friend's death] also the reason why I started working out again, to give those things a place'. This therapeutic effect is also recognized by the key witnesses, saying how, during the act of working out, some issues might rise to the surface, allowing them to freely chat about this and share their problems with each other or the coach. Another key witness confirms this, stating how the young adults 'are more likely to exercise than to ask to see a psychologist'. The importance of creating a safe environment to talk about their issues is illustrated by Derrick (soccer), saying:

> *Communication is key, so you have to talk about things to get somewhere. Some boys wanted someone to talk to who understood them, I noticed that. Me too, because you're telling your story to everyone, but everyone is like: Oh right okay. But if you talk to someone and you can level with them, you start to see things from a different perspective.*

Furthermore, as Derrick's account suggests, it is preferred to have a coach these young adults could relate with. This view is echoed by Wilder (soccer), who wants his coach to be ' someone who, what do you call it, has dealt with the same problems as us', because if that's not the case then, you know, they can't imagine what it's like to be us.'

As these accounts illustrate, it is important for the coaches to not only focus on sports but also on the surrounding behaviors and how these behaviors translate into the everyday lives of the young adults. The key witnesses recognize that putting in the extra effort to create a safe environment is important, as 'not going in for the full hundred percent' might lead to different, less positive outcomes. However, this extra effort is also noticed by the young adults. One participant recognized how at his soccer club, they had a lot of conversations about his home situation and his behavior during soccer training, which helped him to adjust his behavior accordingly. As another young adult summarized:

> *I am usually someone who is quite stubborn, so I mostly do my own thing but I had a trainer who put in quite a lot of energy and effort into me, who had a conversation with me every week and just sat down with me and showed me if I do this and this, then I'm going to get this and this, while if I approach it like this, it can go a lot easier instead of always wanting to do my own thing. He [the coach] says it's sometimes good to follow someone else, so I did that and luckily it turned out well.*

Discussion

The current study examined how physical activity could be used to aid multi-problem young adults with several problems from their own perspective and four key witnesses (i.e., sports coaches and social workers), and what is needed to better support these young adults through sports and exercise. Three themes were uncovered relating to physical activity as a tool to aid with their problems: physical activity can serve as an outlet, it can stimulate personal development, and it can decrease externalizing behavior. However, to do so, several prerequisites needed to be met. Within all these themes, the role of the sports coach became apparent. This study can be seen as an addition to existing qualitative research in vulnerable youth (aged < 22). Although multi-problem young adults differ in problem frequency and severity from vulnerable youth (Haudenhuyse et al., 2013; Vettenburg, 2011; Vettenburg et al., 2013), the current results indicate similar themes pertaining to the role of physical activity.

For multi-problem young adults, physical activity (e.g., soccer, weight training, running) can function as a physical and emotional outlet. It was used as a valuable coping mechanism to deal with their everyday life stressors, aiding the young adults by temporarily diverting their attention, clearing their minds, and allowing them to release tension and energy. These results are in line with a study where young adults considered sports in their vulnerable childhood as an instrument to reduce stress and to better deal with their daily challenges (Super et al., 2017b). The benefits of physical activity as stress reliever have also been found in young adults from the general population (Kim et al., 2014; Koschel et al., 2017), suggesting young adults with and without several problems have similar experiences. However, as multi-problem young adults are confronted with multiple stressors daily (Van der Sluys et al., 2020; Zijlmans et al., 2020) while simultaneity lacking sufficient resilience and other resources (Osgood et al., 2010), having access to physical activity might be more important to them compared to their healthy peers (Haudenhuyse et al., 2013).

The importance of physical activity is underlined in the second theme, using sports and exercise to facilitate positive personal development, including a reduction in externalizing behavior. Physical activity could teach the young adults important life skills such as self-esteem, discipline, and cooperation. In addition, it enabled them to reduce or prevent externalizing behavior (e.g. delinquency, aggression, and substance use), although some young adults reported adverse effects such as increased aggression. Developing life skills can empower multi-problem young adults, increasing their resilience (Holt et al., 2009) and providing them with the tools needed to break the negative cycle of negativity (Hammer & Hyggen, 2010).

Although physical activity can aid multi-problem young adults by offering them resources, it is important to note that resources are also needed to engage in sports and exercise. These means can be practical, like time and money, but they can also be more internal such as willingness, motivation, and sports-related knowledge. Not having these resources could act as a barrier to physical activity participation, for instance when the young adults could not find the determination and perseverance to keep going or when they were too occupied with their problems to be receptive to new experiences.

The sports coach could act as a buffer or completely remove some of these barriers, but only if he was making a conscious effort to create a safe and supporting environment. As an example, this could be by encouraging and motivating the young adults, talking about their problems, or by providing them with the needed knowledge. Having a competent coach could also stimulate feelings of inclusion, success, and competence (Haudenhuyse et al., 2012), which are often lacking in multi-problem young adults (Andrews & Andrews, 2003; Vettenburg, 2011). These results are in line with prior qualitative research on vulnerable (i.e., at-risk) youth, where the sports coach was considered a crucial factor to stimulate positive experiences (Super et al., 2017a) and to generate and maintain a supportive environment (Haudenhuyse et al., 2013). Moreover, similar to a previous study (Haudenhuyse et al., 2012), the current findings suggest that not only the competence and effort, but also the identity of the coach can affect the outcome. Specifically, whereas an identifiable coach (e.g., someone they could level with due to similarities in their backgrounds) could increase the change on positive outcomes, not having such a coach may result in feelings of misunderstanding, which could instigate, rather than alleviate their problems (Super et al., 2017b).

This study is not without limitations. Because convenience sampling was used, there may be limited generalization. The current sample first agreed to participate in research on the effect of physical activity on cognitive control, and later agreed to participate in the interviews. Thus, the experiences of these young adults might, at least partially, differ from other young adults who are less willing to participate in research about physical activity. In addition, due to this selection bias, there may have been a predisposition in the young adults' accounts towards more positive sports-related experiences. Therefore, even though negative outcomes were also reported, caution is advised when interpreting these results. A last limitation could be the heterogeneity of the sample, as the severity of problems can differ, which might have affected the youths' (sports) experiences (Haudenhuyse et al., 2013).

As a final note, it is relevant to consider the interrelatedness of the themes. Physical activity stimulated personal development, which can affect how an individual copes with stressful situations (53). Having more healthy coping strategies, such as using exercise as a diversion and outlet, can in turn help young adults with desistance in externalizing behavior (Giannotta & Weichold, 2016). Moreover, sometimes it was not possible to make a clear distinction in the meaning of physical activity. For example, some young adults reported going for a run to actively decrease their anger, which can be seen as both an exertion of life skills (e.g., recognizing and managing stressors) and as an example of using physical activity as an outlet.

The use of physical activity (programs) to support and develop youth life skills has been a recent topic of interest (Lumpkin, 2011; Makkai et al., 2003; Sandford et al., 2006), yet research on multi-problem youths is scarce and inconclusive (Hermens et al., 2017; Lubans et al., 2012; Super et al., 2018). To date, very few qualitative studies exist, despite the known impact of subjective experiences on positive development (Coakley, 2011; Opstoel et al., 2019; Papacharisis et al., 2005). However, the current findings are in line with an existing qualitative study of young adults who experienced the sports setting in their vulnerable childhood as an important learning environment. Sports were used to develop new skills, but also to enhance previously owned skills by providing them valuable insights (Super et al., 2017b), suggesting the personal development of multi-problem young adults might also benefit from physical activity. Although more research on this topic is needed, the current findings suggest that physical activity can be used to aid multi-problem young adults during emerging adulthood, if certain prerequisites are met. More specifically, in the development of physical activity programs for similar populations, it may be important to take individual characteristics (such as willingness, motivation, but also tendency to aggression or medical background) into account, as these might affect the outcome. In addition, it may be crucial to recognize the role of the coach, including his or her knowledge of physical activity, the ability to do more than only coach a participant on sports-related areas (e.g., stimulating life skills, talking about problems), and the degree in which he or she is identifiable for the participants (for example via a shared cultural background).

In sum, the current results indicate several ways in which physical activity can aid multi-problem young adults during their transition into healthy adulthood, such as by providing them with an outlet for their stress and energy and by stimulating the development of valuable skills and abilities, including those needed to desist from externalizing behavior. To better support these young adults to overcome their daily stressors, it is important to create and maintain a safe, supportive, learning environment with a competent and identifiable coach who is willing to go the extra mile.

Supplement

Table S1 Topic list for semi-structured interviews with multi-problem young adults

1. Introduction
   - Background
   - Objectives
   - Interview information (e.g., duration, recording, anonymity)

2. How are you doing?
   - Physically; mentally?
   - What is your living situation?
   - What are your daytime activities (e.g., hobbies, work, education)?

3. Physical activity (PA):
   - Do you participate in PA (and if yes, what/how long)?
   - Why do people participate in PA?
   - How do you feel about PA?
   - Personal meaning of PA?
   - Do you think that PA can help young adults with problems (e.g., at home or school) to cope better with their problems? (Adapted from Haudenhuyse et al., 2013) How?
   - How can PA aid you?
   - Has PA aided you in the past, and how?
   - Positive & negative experiences PA
   - How would your life be if you had never participated in any type of PA?

4. Questionnaires:
   - Socio-demographics (e.g., age, weight, education)
   - International Physical Activity Questionnaire (IPAQ)
   - WODC Self-reported Delinquency (WODC questionnaire)

Table S2 Overview of type of physical activity engaged in the past and present per participant

Type of physical	Present	Past
Soccer	Derrick, Faiz, John, Rafael, Robert, Wilder	Ahmed, Caleb, Carlos, Juan, Michael
Weight training	Carlos, Juan, Lorenzo, Reda, Robert	Anthony, Michael
Martial arts	Faiz	Derrick (karate), Juan (Taekwondo), Michael (kickboxing, karate, Taekwondo, mixed martial arts), Mohammed (karate, Thai boxing), Rafael (judo), Reda (kickboxing), Wilder (kickboxing)
Walking/running	Carlos, Faiz, Juan, Michael	
Baseball/softball	Rafael, Robert	Caleb
Basketball	John	Caleb
Swimming		Ahmed, Derrick, Michael, Mohammed
Other (i.e., turning, tennis, hockey)		Ahmed, Rafael

Note. Pseudonyms are used

CHAPTER 8

Summary and discussion

The general aim of this dissertation was to investigate the effect of physical activity on (the underlying neurocognitive mechanisms of) heterotypical antisocial behavior in an ecologically valid sample of multi-problem young adults. Earlier research uncovered a robust association between impaired cognitive control and antisocial behavior (Morgan & Lilienfeld, 2000; Ogilvie et al., 2011; Pharo et al., 2011), implying individuals displaying antisocial behavior may benefit from interventions targeting neurocognitive functioning. Impaired cognitive control can severely impact one's life, as it is needed to adequately plan, regulate, and adapt goal-directed behavior (Diamond, 2013; Gazzaley & D'Esposito, 2007; Sira & Mateer, 2014). Understandably, deficiencies in these capabilities may sustain or promote antisocial behavior through the impaired ability to anticipate negative consequences, suppress unwanted impulses, and adjust behavior according to social expectations (Gardner et al., 2008; Loeber et al., 2007; Nigg et al., 2007). Physical activity has been previously proposed as an effective intervention for decreasing antisocial behavior in children and adolescents (aged < 18) from the general population ((Gubbels et al., 2016; Simonton et al., 2018; Spruit et al., 2016) and in clinical adults (i.e., adult offenders or adults suffering from substance use disorders) (Meek, 2018; Wang et al., 2014), yet existing research in young adults (especially clinical or at-risk young adults) is scarce and inconclusive (Hartmann & Depro, 2006; Sampson & Vilella, 2014; Welland et al., 2020). The observed reduction in antisocial behavior may be the result of an enhancement in neurocognitive functioning, as prior studies indicate robust positive effects on cognitive control following increased physical activity in healthy (but sedentary) youth (aged > 18) (Álvarez-Bueno et al., 2017; Liu et al., 2020) and the elderly (65 years or older) (Chen et al., 2020). However, to date, the effect of physical activity on cognitive control has not been examined in young adults suffering from multiple problems (including several forms of antisocial behavior (Hillman et al., 2008; Stillman et al., 2020; Verburgh et al., 2014)), despite their possible associated executive deficits (Jackson & Beaver, 2018; Zijlmans et al., 2019, 2021).

To gain more knowledge on the effectiveness of physical activity interventions in the reduction of antisocial behavior and the possible role of cognitive control in multi-problem young adults, the current thesis included neurobiological and (neuro-)behavioral measures of three indices of cognitive functions, i.e., error processing, response inhibition, and interference, using different measurement techniques including functional magnetic resonance imaging and electroencephalographic paradigms in male multi-problem young adults (aged 18-27). The first two chapters aimed to examine the possible relationship between (neurobiological measures of) cognitive control and behavioral outcomes in the real world (i.e., not examined in the lab), such as engagement in daytime activities a year after completion of a multimodal day treatment program. If such a link exists (e.g., (Steele et al., 2017)), it would advocate for the search for effective interventions enhancing the (presumably) diminished cognitive control in these young adults. The main aim was to examine the association between cognitive control and antisocial behavior in this population. Thus, in Chapters 2 and 3, we assessed neurobiological indices of cognitive control concerning behavior following a multimodal day treatment and antisocial behavior. In Chapter 4, we reviewed and quantified the overall effectiveness of previous physical activity interventions in reducing antisocial behavior. Subsequently, in Chapter 5 and 6, we discussed the association between physical activity and the impact on behavioral measures of cognitive control. And lastly, in Chapter 7, we investigated other ways in which physical activity might contribute to the development of positive behavior and the decrease of negative behavior, according to the multi-problem young adults. This final chapter will discuss the main findings of these studies. In addition, treatment implications, study limitations, and suggestions for future research will be described.

Neurobiological measures of cognitive control

To deepen our fundamental understanding of the possible role of cognitive control in the association between physical activity and antisocial behavior, we first explored the possible potential of neurocognitive biomarkers in the prediction of and association with real-world behavior. To do so, we included three neurobiological indices, i.e., functional brain activity in the anterior cingulate cortex (ACC) during response inhibition and two electroencephalographic measures of error processing, namely error-related negativity (ERN) and error-related positivity (Pe) in a sample of 127 multi-problem young adults.

In **Chapter 2**, we addressed several individual (including psychological, social, and criminal characteristics), neurobehavioral (e.g., task performance) and neurobiological measures (i.e., ACC activity, ERN, and Pe) during response inhibition and error processing at the start of a multimodal day treatment in the prediction of treatment outcomes**.** Overall, we found no association between these predictors and treatment completion and daytime activity participation a year later, indicating limited overall predictive values of the complete models including cognitive control. However, most notably, when controlling for all other predictors, we did find a significant unique association between ACC activity during response inhibition and engaging in daytime activities post-treatment, indicating that multi-problem young adults displaying adequate inhibitory control (Kerns et al., 2004) at the start of their treatment showed a better chance on a positive outcome (e.g. daytime participation) a year later. These results are in line with a prior study where heightened ACC activity during response inhibition was related to lower odds of recurrent antisocial behavior (indexed as approximately half of the number of re-arrests) in adult offenders compared to those with lowered ACC activity (Aharoni et al., 2013). Although preliminary and considering that the overall prediction model containing all cognitive control measurements was not significant, these findings suggest that cognitive control, specifically inhibitory control-related activity in the ACC might be a potentially viable neurocognitive biomarker of behavioral improvement in populations displaying antisocial behavior (Zijlmans et al., 2021). Moreover, this raises the question if interventions modulating inhibitory control such as exercise interventions would lead to more positive behavioral outcomes (Erickson et al., 2015; Voss et al., 2011; Wu et al., 2022).

To further examine the value of neurocognitive biomarkers, we then studied if the ERN during error processing could serve as a protective or facilitating factor in the association between self-serving cognitive distortions (i.e., pro-criminal biases) and antisocial behavior (**Chapter 3**). Indeed, we found an association between self-serving cognitive distortions (specifically those related to an egocentric bias) and different forms of self-reported antisocial behavior, suggesting such biases are important in the prevention and treatment of antisocial behavior. However, this association was not moderated by error processing, indicating the intact or impaired ability to exert self-control and self-regulation did not subsequently prevent or promote antisocial behavior (Caprara et al., 2007; Gardner et al., 2008; Loeber et al., 2007; Nigg et al., 2007; Siever, 2008). This may be due to a difference in time of occurrence between the more early and automated ERN (25-100 ms after the response) versus the slower and conscious processing of social information including self-serving cognitive distortions (in this study measures by means of self-report) (Bernstein et al., 1995; Crick & Dodge, 1994).

Although our results indicate no moderating effect of the current neurobiological measures of error processing, it is still worthwhile to examine effective interventions enhancing cognitive control. As previously mentioned, there is accumulating evidence for an association between impaired neurocognitive functioning and antisocial behavior (Morgan & Lilienfeld, 2000; Ogilvie et al., 2011; Pharo et al., 2011). This is supported by our findings in **Chapter 5**, where we confirmed impaired cognitive control in the heterogeneous group of multi-problem young adults compared to age- and sex-matched peers from the general population. It is therefore possible that cognitive control as a higher-order cognition still affects other cognitive processes related to (negative) behavior, yet not as a moderator between distorted thinking and antisocial behavior (Van Nieuwenhuijzen et al., 2017; Van Nieuwenhuijzen & Vriens, 2012).

The chapters presented thus far suggest neurobiological screening and possibly altering of inhibitory control-related brain activity might aid multi-problem young adults with their reintegration after treatment. Enhancing neurocognitive functioning (for example through interventions modulating neuronal networks, encompassing among others the ACC) can be especially relevant for individuals with observed neurocognitive deficits such as those displaying antisocial behavior (Morgan & Lilienfeld, 2000; Ogilvie et al., 2011; Pharo et al., 2011; Zijlmans et al., 2019, 2021). For them, increased executive control can potentially promote decreased socially unwanted behavior through the regained ability to regulate and suppress their (externalizing) behavior (Gardner et al., 2008; Loeber et al., 2007; Nigg et al., 2007). A possible effective intervention targeting executive functions is through increased physical activity (Gomez-Pinilla & Hillman, 2013; Verburgh et al., 2014). Indeed, prior neuroimaging studies indicate exercise-induced changes in structural volume (e.g., increased cortical volume and thickness) and neural activity (e.g., increased neural efficiency during inhibition) in the prefrontal cortex and ACC (Erickson et al., 2015; Voss et al., 2011; Wu et al., 2022). Less established is the causal link between these brain changes and behavioral changes, yet some evidence for this relationship exists (e.g., (Oby et al., 2019)). In addition, we should be careful not to overvalue neurobiological findings related to behavior (Jurjako et al., 2018) due to the complications that arise when translating such measures to real-world behavior (Marincola, 2003). Assessing a causal relation between exercise-induced changes in neurocognitive functioning in control and behavior therefore requires multiple steps, including exploring the effect of physical activity interventions on cognitive control. Accordingly, a first step towards a causal model was examined in the following chapters, using behavioral indices of cognitive control to facilitate an easier translation (as opposed to neurobiological indices). As such, we now transition from the more fundamental chapters, which explored the association between neurobiological markers of cognitive control and behavior to the more practical chapters, which delve into the effect of physical activity on behavioral markers of cognitive control.

Physical activity and cognitive control

The aim of the remaining chapters was thus to gain more knowledge on the practical implications and possible treatment effects of physical activity interventions on antisocial behavior and (behavioral measurements of) cognitive control.

We therefore reviewed and quantified existing literature on the effect of physical activity interventions on a broad category of antisocial behaviors in children and adults (**Chapter 4**).

Comparing treatment effects of 20 studies, we found an overall small-to-medium effect in favor of physical activity, indicating larger reductions in antisocial behavior in individuals participating in physical activity interventions compared to waitlist or sedentary-attention controls. This effect was moderated by type of antisocial behavior. Specifically, for studies using anger and/or hostility as antisocial outcome measure, the effect was larger compared to other types of antisocial behavior including aggressive behavior and other externalizing behavior, supporting the importance of addressing antisocial behavior as a heterogeneous construct. Other moderating effects were found for type of control group (i.e., larger effects for comparisons with waitlist versus with sedentary attention) and type of activity (i.e., larger effects for interventions containing walking, jogging, or running as main activity versus vs other types of physical activity such as team sports or aerobic-based exercises). In sum, physical activity interventions can be effective in the reduction of antisocial behavior.

Given the positive effect of physical activity interventions on antisocial behavior and the robust known association between cognitive control deficits and antisocial behavior (Morgan & Lilienfeld, 2000; Ogilvie et al., 2011; Pharo et al., 2011), a plausible next step is to investigate the effect of physical activity on cognitive control. Prior experimental studies suggest increased physical activity can enhance neurocognitive functioning, especially in healthy but sedentary (older) adults (Colcombe & Kramer, 2003; Hillman et al., 2008; Voss et al., 2011). Additionally, several cross-sectional studies in healthy young adults have observed a positive association between (self-reported) physical activity and (neuro-)behavioral measures of cognitive control, with relatively better executive functions in active young adults compared to their inactive peers (Giles et al., 2017; Goenarjo et al., 2020; Padilla et al., 2014). Following these studies conducted in the general population, we were interested to see if such results can be replicated in populations displaying antisocial behavior.

To examine this, we first explored the possible association between self-reported physical activity and behavioral measures of three indices of cognitive control (i.e., response inhibition, error processing, and interference effect) in **Chapter 5**. We also compared the multi-problem sample (n = 63) with age- and sex-matched controls (n = 62) from the general population. Within the multi-problem young adult group, results indicate no association between self-reported baseline physical activity levels and the selected behavioral measures of executive functioning at the start of their multimodal day treatment program, suggesting more active young adults did not display better cognitive control compared to less active young adults. However, compared to their peers from the general population, we did find impaired neurocognitive functioning in the multi-problem group, especially impaired response inhibition and decreased task performance (indexed as relatively less difference in reaction time between correct and incorrect trials) on an error processing task, regardless of physical activity levels. In addition, we found comparable results of relatively high levels of physical activity between the multi-problem group and the controls, indicating that, whilst unexpected, multi-problem young adults show relatively active lifestyles, similar to the young adults from the general population in our control sample. This is in contrast with prior studies where most young adults failed to meet the World Health Organization guidelines on daily exercise (Marques et al., 2015; Song et al., 2013). The current study was the first to explore levels of physical activity in a multi-problem sample with impaired cognitive control, providing valuable information on their lifestyle habits.

In the following study (**Chapter 6**) we examined the possibility to enhance neurocognitive functioning (using the same behavioral measures of response inhibition, error processing, and cognitive interference) through increased physical activity in our already relatively high-active group of multi-problem young adults with cognitive control deficits. Using a randomized controlled (RCT) design with a light-active and moderate-active physical activity group, we subjected the participants to six weeks of physical activity intervention embedded in a larger multimodal day treatment program. Some caution is advised in interpreting the following results, as only a small number of participants completed the follow-up measures (N = 23) and because the intervention structure (embedded in a larger treatment program) complicated any definite statements about the causal effect of our physical activity intervention. However, we did uncover an overall effect after the embedded physical activity intervention on cognitive control, particularly improved response inhibition, improved task performance (i.e., higher accuracy) on an error-processing task, and improved (i.e., decreased) cognitive interference after six weeks. We found no difference between treatment intensity, indicating the light-active and moderate-active groups both benefitted equally. The lack of a difference in treatment effect between these two groups may be due to confounding factors (discussed in more detail in the limitations section). As such, future studies are needed to replicate these results, taking into account these limitations. Notwithstanding, the current findings can still be seen as a contribution to the literature suggesting physical activity (embedded in a larger treatment program) may indeed be an effective treatment targeting cognitive control in at-risk populations, even at a light intensity and in already relatively high-active individuals.

To summarize, we established that physical activity interventions can be effective in the reduction of antisocial behavior based on prior studies (Chapter 4). We then confirmed high levels of self-reported physical activity and impaired cognitive control in this sample of multi-problem young adults (Chapter 5). And lastly, we found that even within this already relatively high-active group, we can enhance cognitive control independently of treatment intensity using a 6-week physical activity intervention embedded in a multimodal day treatment program (Chapter 6).

Beyond physical activity interventions: experiences of multi-problem young adults

Our results, taken together with previous studies indicate the possible benefits of physical activity in the reduction of antisocial behavior. Much of what is known about these potential benefits comes from quantitative research. Whilst providing us with valuable insights, such research does not allow for the interpretation of the subjective experience of physical activity. It has been previously proposed that not the act of participation itself, but rather the experience is key to facilitating positive behavioral outcomes (Coakley, 2011; Opstoel et al., 2019; Papacharisis et al., 2005). As such, it is important to not only focus on the quantitative outcomes but to also examine possible qualitative outcomes related to physical activity.

Thus, in **Chapter 7**, we conducted a qualitative follow-up study using semi-structured interviews with a subset of the multi-problem young adults (N = 15), during which we interviewed them about their experiences with physical activity, the meaning of physical activity, and how they perceived it could support them in coping with their problems. Using a thematic approach (Braun & Clarke, 2006), we discovered three interrelated themes explaining how physical activity can contribute to positive behavior and decrease negative behavior. That is, physical activity can serve as an outlet, it can stimulate personal development, and it can decrease externalizing behavior, but only if participants felt safe and supported by the sports coach.

Despite the increased interest in physical activity and exercise programs to stimulate youth personal development (Lumpkin, 2011; Makkai et al., 2003; Sandford et al., 2006), to the authors' knowledge, there is only limited qualitative research including youth or young adults with a vulnerable or complex background (Haudenhuyse et al., 2013; Super et al., 2017b, 2017a). The current findings are largely in line with these prior studies, indicating both vulnerable (i.e., at risk of becoming multi-problem) youth and multi-problem young adults (i.e., suffering from a plethora of problems) may benefit from physical activity.

Main conclusion

The current thesis explored the effect of physical activity on antisocial behavior and the possible role of cognitive control. Our findings suggest that overall, increased physical activity may be used to treat antisocial behavior in adults displaying a range of externalizing behaviors. Furthermore, regarding cognitive control, our results first associated a neurocognitive biomarker (ACC activity during response inhibition) with better outcomes (higher odds of engaging in daytime activities) a year after a multimodal day treatment program in populations displaying antisocial behavior, linking cognitive control to real-world positive behavior. Secondly, our data suggest enhanced neurocognitive functioning following a physical activity program in young adults with impaired cognitive control, who are suffering from multiple problems, including aggression, delinquent behavior, frequent substance use, and other externalizing behaviors. Taken together with prior studies, the results of the current dissertation suggest that a: physical activity interventions and programs may possibly provide easy-to-implement treatment of antisocial behavior and b: this positive behavioral effect may be partially explained by an exercise-induced enhancement of cognitive control, although future studies including both cognitive control and antisocial behavior are needed to verify this hypothesis.

Limitations

Some general limitations should be noted. Most notable is the fact that our physical activity intervention in Chapter 6 was embedded in a larger multimodal day treatment program (i.e., cognitive behavioral therapy and education), thus hampering any definite conclusions about the isolated effect of physical activity. Based on (limited) existing research, there are no indications that the other individual aspects of the treatment program affect cognitive control (Vandborg et al., 2015; Virta, 2010) nor does the curriculum contain any of the other known effective approaches (i.e., mindfulness (Larson et al., 2013)) in addition to the present physical activity intervention (Stern et al., 2019). This suggests that the increased physical activity may have played at least a partial role in the observed cognitive control enhancement. An exercise program independent of any other treatment programs would have enabled us to give a more accurate description of the effect of physical activity. Adding a sedentary-control group without exercise would have further aided us towards this aim, as it would have enabled us to discern treatment effects versus random (attention) effects. However, due to the very nature of our population of interest (emerging young adults with complex problems), it would have been increasingly more difficult to recruit them outside the context of an existing treatment program.

Concerning recruitment and retention, it is important to discuss the relatively low percentage of participants completing follow-up measurements after six weeks. Some external factors were at play, such as the high number of participants dropping out of the multimodal treatment within their first two weeks (before or just after baseline testing), the high frequency of moving and changing telephone numbers, and the Covid-19 pandemic. More importantly, there were also some internal reasons which in hindsight, we could have done differently. For example, our participant recruitment and maybe also retention would have benefitted from a more established relationship between the researchers and the eligible young adults. Indeed, halfway we acknowledged this problem and started joining the physical activity lessons with the multi-problem young adults, which resulted in more young adults showing interest in the research. Although not measured, we did observe a relative increase in young adults joining our study. It is unclear if this would have increased the number of participants finishing follow-up measurements, as we had to preliminary discontinue our data collection due to the pandemic.

Another limitation is the selection of our participants, as all treatment-seeking young adults showed relatively high levels of self-reported physical activity at the start of their treatment (as described in Chapter 5). This may be due to a biased selection process, where only those with an interest in sports and exercise were willing to participate in our study, although all physical activity lessons were mandatory independent of study participation. In addition, their already active lifestyle may lead to the discussion of why these young adults are still displaying cognitive control deficits and relatedly, are suffering from multiple problems including externalizing behavior. Because we did not measure antisocial behavior at baseline, it remains unclear if these young adults are in fact already showing positive changes in their behavior following their observed active lifestyle. Arguably, the enriched environment presented by the multimodal day treatment may also play a role in this and as such, more longitudinal studies are needed to examine if increased neurocognitive functioning following increased physical activity, even in high-active young adults, can result in decreased antisocial behavior.

Treatment implications and recommendations

Taking into consideration these factors, there are some implications for practice and future studies. Firstly, most pertinent to this thesis, the current findings suggest that physical activity may serve as an effective treatment in the reduction of different antisocial behaviors in (young) adults displaying these behaviors. This conclusion was drawn using both quantitative (Chapter 4) and qualitative (Chapter 7) data and is in line with prior studies in children and adolescents (Harwood et al., 2017; Spruit et al., 2016), demonstrating the overall positive effects of physical activity on externalizing and negative behavior. Such positive results need to be interpreted with caution, as the activity needs to meet certain recommendations such as creating a safe and stimulating environment with a relatable coach. Similar conclusions are drawn in other studies including vulnerable populations (Haudenhuyse et al., 2013; Super et al., 2017a, 2017b), indicating special attention should be paid to the how and where of physical activity programs. Despite the growing evidence of these (mostly) positive exercise-induced effects and the high self-reported physical activity of our group of multi-problem young adults, many other young adults fail to meet the guidelines of the World Health Organization for exercise (Marques et al., 2015; Song et al., 2013). The outcomes of this dissertation together with prior studies call for increased attention to effective programs encouraging young adults, especially those displaying antisocial behavior to participate in physical activities. Furthermore, it is also important to consider how physical activity can stimulate positive behavioral changes, as the underlying mechanisms (including neurocognitive functioning) are complex and in need of more research. For example, it remains unclear if the improvement in behavior after physical activity is mediated by enhanced executive functions, as this was not measured in the current thesis.

Additionally, it may be worthwhile to examine the effect of physical activity in other populations with impaired neurocognitive functions, such as those suffering from Attention Deficit/Hyperactivity Disorder or brain trauma, as they might also benefit from increased physical activity (Varigonda et al., 2021). Based on this dissertation, it is recommended to combine neuroimaging and behavioral measurements to ascertain if physical activity can affect neurobiological indices of cognitive control such as ACC activity during inhibition, as our results indicate a direct association between treatment outcome and inhibition-induced ACC activity.

And last, although impaired cognitive control is associated with antisocial behavior, it is not yet clear if enhanced cognitive control would also lead to decreased antisocial behavior. Assuming a positive effect of physical activity on cognitive control, the next logical step would be to examine if this cognitive control enhancement would lead to reduced antisocial behavior, for example by including a follow-up measuring changes in antisocial behavior. Ideally, this would be a study implementing a physical activity program with at least two groups (exercise versus no exercise). Furthermore, as our sample of young adults already displayed relatively high levels of (self-reported) physical activity, it would be valuable to include both sedentary and high-active participants and to use different exercise intensities. This would establish whether there is a possible dose-response relation between physical activity and cognitive control. Additionally, the use of (preferable multiple) valid and robust instruments to measure physical activity levels and intensity (e.g., VO2 max), having a clear exercise protocol (e.g., only changing intensity between different groups), and having a coach to which the participants can relate (e.g., based on shared cultural background) would further aid towards this goal.

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Nederlandse samenvatting

Achtergrond

Dit proefschrift onderzocht het effect van fysieke activiteit op (de onderliggende neurocognitieve processen van) verschillende vormen van antisociaal gedrag in multi-probleem jongvolwassenen. Eerder onderzoek wijst op een robuuste relatie tussen verminderde cognitieve controle en antisociaal gedrag (Morgan & Lilienfeld, 2000; Ogilvie et al., 2011; Pharo et al., 2011), wat suggereert dat individuen met antisociaal gedrag mogelijk voordeel kunnen ondervinden van interventies gericht op het verbeteren van neurocognitief functioneren. Verminderde cognitieve controle kan iemands leven ernstig verstoren, aangezien dit neurocognitieve proces nodig is voor het adequaat plannen, reguleren en aanpassen van gedrag (Diamond, 2013; Gazzaley & D'Esposito, 2007; Sira & Mateer, 2014). Het is begrijpelijk dat tekortkomingen in deze vaardigheden mogelijk bijdragen aan het in stand houden of veroorzaken van antisociaal gedrag, omdat het leidt tot het verminderde vermogen om negatieve gevolgen te anticiperen, ongewenste impulsen te onderdrukken en gedrag te veranderen op basis van sociale verwachtingen (Gardner et al., 2008; Loeber et al., 2007; Nigg et al., 2007). Fysieke activiteit is eerder voorgesteld als een effectieve behandeling voor het verminderen van antisociaal gedrag bij kinderen en adolescenten (< 18 jaar) uit de algemene bevolking (Gubbels et al., 2016; Simonton et al., 2018; Spruit et al., 2016) en bij volwassen delinquenten of volwassenen die lijden aan middelenverslaving (Meek, 2018; Wang et al., 2014). Bestaand onderzoek bij jongvolwassenen (vooral klinische of hoog-risico jongvolwassenen) is echter schaars en geeft wisselende resultaten (Hartmann & Depro, 2006; Sampson & Vilella, 2014; Welland et al., 2020). De vermindering in antisociaal gedrag die optreedt na het volgen van een bewegingsinterventie is mogelijk het resultaat van een verbetering in neurocognitief functioneren. Eerdere studies tonen een positief effect aan van fysieke activiteit op cognitieve controle in gezonde (maar sedentaire) jongeren onder de 18 jaar (Álvarez-Bueno et al., 2017; Liu et al., 2020) en bij ouderen van boven de 65 jaar (Chen et al., 2020). Tot op heden is het effect van fysieke activiteit op cognitieve controle echter nog niet onderzocht in jongvolwassenen die lijden aan meerdere problemen (waaronder verschillende vormen van antisociaal gedrag) (Hillman et al., 2008; Stillman et al., 2020; Verburgh et al., 2014), ondanks de executieve tekortkomingen die daar mogelijk mee samenhangen (Jackson & Beaver, 2018; Zijlmans et al., 2019, 2021).

Om meer kennis te verwerven over de effectiviteit van bewegingsinterventies in het verminderen van antisociaal gedrag en de mogelijke rol van cognitieve controle in multi-probleem jongvolwassenen, richtte dit proefschrift zich op drie vormen van neurocognitieve functies, namelijk foutverwerking, responsinhibitie en interferentie. Hiervoor maakten we gebruik van verschillende meettechnieken, waaronder functionele magnetische resonantiebeeldvorming en elektro-encefalografie bij jongvolwassenen met meerdere problemen (leeftijd 18 - 27 jaar). De eerste twee hoofdstukken onderzochten de mogelijke relatie tussen cognitieve controle en gedrag in de echte wereld (d.w.z. niet onderzocht in het laboratorium), zoals deelname aan dagactiviteiten een jaar na voltooiing van een multimodaal dagprogramma. Als zo'n verband bestaat (bijv. (Steele et al., 2017)), zou het pleiten voor het zoeken naar effectieve interventies die de (vermoedelijk) verminderde cognitieve controle bij deze jonge volwassenen verbeteren. Het belangrijkste doel was om het verband tussen cognitieve controle en antisociaal gedrag in deze populatie te onderzoeken. Zo hebben we in hoofdstuk 2 en 3 neurobiologische indicatoren van cognitieve controle onderzocht met betrekking tot behandeluitkomsten en antisociaal gedrag. In hoofdstuk 4 hebben we de algehele effectiviteit van eerdere interventies op het gebied van lichaamsbeweging in de vermindering van antisociaal gedrag beoordeeld en gekwantificeerd. Vervolgens bespraken we de associatie met, en het effect van fysieke activiteit op gedragsmetingen van cognitieve controle in de hoofdstukken 5 en 6. In het laatste wetenschappelijke hoofdstuk (7) onderzochten we andere manieren waarop fysieke activiteit zou kunnen bijdragen aan de ontwikkeling van positief gedrag en de afname van negatief gedrag, volgens de multi-probleem jongvolwassenen zelf. In het huidige slothoofdstuk worden de belangrijkste bevindingen van deze onderzoeken besproken.

Samenvatting van de resultaten

Neurobiologische maten van cognitieve controle

In hoofdstuk 2 hebben we gekeken naar verschillende individuele (waaronder psychologische, sociale en criminele kenmerken), neurogedragsmatige (bijv. taakprestatie) en neurobiologische metingen in multi-probleem jongvolwassenen bij aanvang van een multimodale dagbehandeling (N = 127). De neurobiologische metingen bestonden uit hersenactiviteit in de anterieure cingulate cortex (ACC) tijdens responsinhibitie en twee elektrofysiologische hersenreacties (ERN en Pe) gerelateerd aan foutverwerking. We hebben onderzocht of we aan de hand van deze metingen een model konden opstellen in de voorspelling van behandeluitkomsten. Over het algemeen vonden we geen verband met deze voorspellers en het voltooien van de behandeling en ook niet met hun deelname aan dagactiviteiten zoals werk of school een jaar later, wat wijst op een beperkte algehele voorspellende waarde van de volledige modellen inclusief cognitieve controle. Daarentegen staat wel het opvallende resultaat dat, onder constant houding van alle andere voorspellers, we een significante unieke associatie vonden tussen ACC-activiteit tijdens responsinhibitie en het hebben van dagactiviteiten na de behandeling. Dit betekent dat de multi-probleem jongvolwassenen met adequate responsinhibitie (Kerns et al., 2004) tijdens de start van hun behandeling een betere kans hebben op een positieve uitkomst (bijvoorbeeld deelname aan dagbesteding) een jaar na hun behandeling, vergeleken met de multi-probleem jongvolwassenen met minder goed werkende responsinhibitie. Deze resultaten komen overeen met een eerdere studie waarin verhoogde ACC-activiteit tijdens responsinhibitie gerelateerd was aan een lagere kans op terugkerend antisociaal gedrag (gehalveerd aantal hernieuwde arrestaties) bij volwassen delinquenten in vergelijking met degenen met verminderde ACC-activiteit (Aharoni et al., 2013). Hoewel deze resultaten moeten worden beschouwd als voorlopig en rekening houdend met het feit dat het algehele voorspellingsmodel met alle metingen van cognitieve controle niet significant was, suggereren deze bevindingen dat cognitieve controle, met name inhiberende hersenactiviteit in de ACC, mogelijk een bruikbare neurocognitieve biomarker zou kunnen zijn voor gedragsverbetering in populaties die antisociaal gedrag vertonen. Bovendien roept dit de vraag op of interventies gericht op het moduleren van cognitieve controle (specifiek responsinhibitie), zoals bewegingsinterventies, mogelijk kunnen leiden tot positievere behandeluitkomsten (Erickson et al., 2015; Voss et al., 2011; Wu et al., 2022).

Om de waarde van neurocognitieve biomarkers verder te onderzoeken, hebben we in hoofdstuk 3 vervolgens onderzocht of een van de genoemde hersenreacties tijdens het verwerken van fouten (ERN) kan dienen als een beschermende of faciliterende factor in de associatie tussen cognitieve denkfouten (pro-criminele vooroordelen) en antisociaal gedrag. We vonden inderdaad een verband tussen (egocentrisch-gerelateerde) denkfouten en verschillende vormen van zelfgerapporteerd antisociaal gedrag, wat suggereert dat dergelijke vooroordelen belangrijk zijn bij de preventie en behandeling van antisociaal gedrag. Deze associatie werd echter niet beïnvloed door foutverwerking. In andere woorden, het intacte of verminderde vermogen om zelfregulatie uit te oefenen speelt geen rol in het voorkomen of bevorderen van antisociaal gedrag (Caprara et al., 2007; Gardner et al., 2008; Loeber et al., 2007; Nigg et al., 2007; Siever, 2008). Dit is mogelijk door een verschil in tijd van optreden tussen de relatief snelle en geautomatiseerde ERN (25-100 ms na de respons) versus de langzamere en meer bewustere verwerking van sociale informatie waarvan cognitieve denkfouten een onderdeel zijn (Bernstein et al., 1995; Crick & Dodge, 1994).

Ondanks het ontbreken van een interactie tussen de huidige maten van cognitieve controle (gerelateerd aan foutverwerking) en antisociaal gedrag, is het nog steeds nuttig om te zoeken naar effectieve interventies gericht op verbetering van cognitieve controle. Zoals eerder aangegeven, is er voldoende bewijs voor een relatie tussen verminderd neurocognitief functioneren en antisociaal gedrag (Morgan & Lilienfeld, 2000; Ogilvie et al., 2011; Pharo et al., 2011). Dit is in lijn met onze eigen bevindingen in hoofdstuk 5, waar we zoals verwacht verminderde cognitieve controle vonden in onze groep met multi-probleem jongvolwassenen vergeleken met jongvolwassenen uit de algemene populatie zonder problemen (gematcht op leeftijd en geslacht). Het is dus mogelijk dat cognitieve controle als overkoepelende mentale functie nog steeds een rol speelt bij andere mentale processen gerelateerd aan (ongewenst) gedrag, maar dan niet als modererende factor tussen cognitieve denkfouten en antisociaal gedrag (Van Nieuwenhuijzen et al., 2017; Van Nieuwenhuijzen & Vriens, 2012).

De tot zover gepresenteerde hoofdstukken suggereren dat neurobiologische screening en eventuele aanpassing van hersenactiviteit gerelateerd aan responsinhibitie mogelijk een positieve rol kunnen spelen bij het terugkeren naar de samenleving na behandeling van multi-probleem jongvolwassenen. Verbeterd neurocognitief functioneren (bijvoorbeeld via interventies met een effect op neurale netwerken waaronder de ACC) kan met name relevant zijn voor individuen met geobserveerde neurocognitieve tekortkomingen, zoals populaties met antisociaal gedrag (Morgan & Lilienfeld, 2000; Ogilvie et al., 2011; Pharo et al., 2011; Zijlmans et al., 2019, 2021). Voor deze personen kan verbeterde executieve controle mogelijk leiden tot verminderd sociaal ongewenst gedrag, via de verhoogde vaardigheid om (externaliserend) gedrag te reguleren en onderdrukken (Gardner et al., 2008; Loeber et al., 2007; Nigg et al., 2007).

Het verhogen van fysieke activiteit kan een mogelijke effectieve interventie zijn gericht op verbetering van executieve functies (Gomez-Pinilla & Hillman, 2013; Verburgh et al., 2014). Eerdere neuroimaging-onderzoeken wijzen inderdaad op structurele veranderingen in de hersenen zoals toegenomen corticaal volume en dikte en veranderingen in neurale activiteit (bijv. verhoogde neurale efficiëntie tijdens inhibitie) in de prefrontale cortex en ACC (Erickson et al., 2015; Voss et al., 2011; Wu et al., 2022) na verhoging van fysieke activiteit. Minder bekend is of deze hersenveranderingen ook kunnen leiden tot gedragsveranderingen, hoewel er enig bewijs is voor dit effect (bijv. (Oby et al., 2019)). Daarbij geldt wel dat we moeten oppassen met de overschatting van neurobiologische bevindingen gerelateerd aan gedrag (Jurjako et al., 2018), vanwege de gecompliceerde vertaling van dergelijke (vaak experimentele) metingen naar gedrag in de echte wereld (Marincola, 2003). Het beoordelen en mogelijk vaststellen van een causaal verband vereist daarom meerdere stappen, waaronder het onderzoeken van het effect van fysieke activiteitsinterventies op cognitieve controle. Om die reden werd in de volgende hoofdstukken een eerste stap naar een causaal model onderzocht, waarbij we gebruik maken van gedragsindices (versus neurobiologische indices) van cognitieve controle om de vertaling te vergemakkelijken. Als zodanig gaan we nu over van de meer fundamentele hoofdstukken (waarin het verband tussen neurobiologische markers van cognitieve controle en gedrag wordt onderzocht) naar het meer op de praktijk gebaseerde deel (waarin het effect van fysieke activiteit op gedragsmarkers van cognitieve controle wordt onderzocht).

Fysieke activiteit en cognitieve controle

Het doel van de resterende hoofdstukken was dus om meer kennis te vergaren over de praktische implicaties en mogelijke behandeleffecten van fysieke activiteitsinterventies op antisociaal gedrag en (gedragsmetingen van) cognitieve controle.

In hoofdstuk 4 hebben we de bestaande literatuur over het effect van bewegingsinterventies op verschillende vormen van antisociaal gedrag bij kinderen en volwassenen beoordeeld en gekwantificeerd. Door de behandeleffecten van 20 bestaande onderzoeken te vergelijken, vonden we een algemeen klein tot middelgroot effect in het voordeel van fysieke activiteit, wat wijst op een grotere vermindering van antisociaal gedrag bij individuen die deelnemen aan fysieke activiteitsinterventies in vergelijking met personen zonder interventie of met een interventie zonder fysieke activiteit met vergelijkbare contacturen. Dit effect werd gemodereerd door het type antisociaal gedrag. Dat betekent dat we grotere effecten vonden in studies die woede en/of vijandigheid gebruikten als antisociale uitkomstmaat vergeleken met andere soorten antisociaal gedrag, waaronder agressief gedrag en ander externaliserend gedrag. Dit resultaat benadrukt dat het essentieel is om antisociaal gedrag op verschillende manieren te meten. Andere modererende effecten waren het type controlegroep (d.w.z. grotere effecten voor vergelijkingen met geen interventie versus met een andere, niet fysieke activiteitsinterventie) en type activiteit (d.w.z. grotere effecten voor interventies met wandelen, joggen of hardlopen als hoofdactiviteit versus andere types van fysieke activiteit zoals teamsport of aerobe oefeningen). Kortom, interventies gebaseerd op fysieke activiteit kunnen effectief zijn in het verminderen van antisociaal gedrag.

Gezien het positieve effect van bewegingsinterventies op antisociaal gedrag en de sterke bestaande associatie tussen cognitieve controletekorten en antisociaal gedrag (Morgan & Lilienfeld, 2000; Ogilvie et al., 2011; Pharo et al., 2011), lijkt de volgende logische stap om het effect van fysieke activiteit op cognitieve controle te onderzoeken. Eerdere experimentele studies suggereren dat verhoogde fysieke activiteit het neurocognitief functioneren kan verbeteren, vooral bij gezonde maar sedentaire (oudere) volwassenen (Colcombe & Kramer, 2003; Hillman et al., 2008; Voss et al., 2011). Bovendien hebben verschillende cross-sectionele onderzoeken bij gezonde jonge volwassenen een positief verband gevonden tussen (zelfgerapporteerde) fysieke activiteit en (neuro-)gedragsmetingen van cognitieve controle, met relatief betere executieve functies bij actieve jonge volwassenen in vergelijking met hun inactieve leeftijdsgenoten (Giles et al., 2017; Goenarjo et al., 2020; Padilla et al., 2014). Gebaseerd op deze studies lijkt er een correlatie te bestaan tussen fysieke activiteit en cognitieve controle in de algemene bevolking. Het is echter nog niet duidelijk of dit ook geldt voor individuen die antisociaal gedrag vertonen.

Daarom onderzochten we in hoofdstuk 5 eerst het mogelijke verband tussen zelfgerapporteerde fysieke activiteit en gedragsmetingen van drie indices van cognitieve controle (d.w.z. responsinhibitie, foutverwerking en interferentie-effect) in multi-probleem jongvolwassenen tijdens de start van een multimodaal dagprogramma (n = 63). We vonden geen verband tussen zelfgerapporteerde fysieke activiteitsniveaus en de geselecteerde maten van executief functioneren bij jongvolwassenen met meerdere problemen, wat suggereert dat actievere jongvolwassenen geen betere cognitieve controle vertoonden dan de minder actieve jongvolwassenen. Daarnaast vergeleken we deze multi-probleem groep met op leeftijd en geslacht afgestemde controles uit de algemene bevolking (n = 62) op fysieke activiteit en cognitieve controle. We vonden een verminderd neurocognitief functioneren bij de multi-probleem jongvolwassenen in vergelijking met hun leeftijdsgenoten uit de algemene bevolking, namelijk verminderde responsinhibitie en verminderde taakprestatie (relatief minder verschil in reactietijd tussen correcte en incorrecte trials) op een foutverwerkingstaak. Deze resultaten waren onafhankelijk van het niveau van fysieke activiteit. Daarnaast vonden we vergelijkbare resultaten van relatief hoge niveaus van fysieke activiteit tussen de multi-probleemgroep en de controlegroep, wat erop wijst dat, hoewel onverwacht, multi-probleem jongvolwassenen een relatief actieve levensstijl hebben vergelijkbaar met jongeren van dezelfde leeftijd zonder problemen. Dit staat in contrast met eerdere studies waarin de meeste jonge volwassenen niet voldoen aan de richtlijnen van de Wereldgezondheidsorganisatie voor dagelijkse lichaamsbeweging (Marques et al., 2015; Song et al., 2013). De huidige studie is de eerste die de niveaus van fysieke activiteit onderzocht in een steekproef van jongvolwassenen met meerdere problemen en verminderde cognitieve controle, wat waardevolle informatie oplevert over hun levensstijl.

In de daaropvolgende studie (hoofdstuk 6) onderzochten we de mogelijkheid om het neurocognitief functioneren te verbeteren (gemeten met dezelfde gedragsmaten van responsinhibitie, foutverwerking en cognitieve interferentie uit hoofdstuk 5) door de fysieke activiteit te verhogen in onze toch al relatief actieve groep van multi-probleem jongvolwassenen met verminderde cognitieve controle. Met behulp van een gerandomiseerd gecontroleerd (RCT) ontwerp met een licht-actieve en matig-actieve fysieke activiteitsgroep, onderwierpen we de deelnemers aan zes weken fysieke activiteitsinterventie ingebed in een groter multimodaal dagbehandelingsprogramma. Enige voorzichtigheid is geboden bij het interpreteren van de resultaten, aangezien slechts een klein aantal deelnemers de metingen na zes weken voltooiden (N = 23) en omdat de structuur van het onderzoek (sportinterventie ingebed in een groter behandelprogramma) het moeilijk maakt om de causale effecten van beweging te isoleren. Ondanks deze limitaties ontdekten we een algemeen effect van de fysieke activiteitsinterventie (als onderdeel van het bredere behandelprogramma) op cognitieve controle, met name verbeterde responsinhibitie, verbeterde taakprestaties (d.w.z. hogere nauwkeurigheid) bij een foutverwerkingstaak en verbeterde (d.w.z. verminderde) cognitieve interferentie na zes weken sporten. We vonden echter geen verschil tussen de behandelingsintensiteit, wat aangeeft dat de licht-actieve en matig-actieve groepen beide evenveel baat hadden van de interventie. Het ontbreken van een verschil in behandeleffect tussen deze twee groepen kan te wijten zijn aan verstorende factoren zoals het ontbreken van een verschil in hartslag tijdens sporten tussen de twee groepen, wat erop wijst dat de groepsactiviteiten mogelijk te veel op elkaar leken. Er zijn dus vervolgstudies nodig om deze resultaten te repliceren, rekening houdend met deze beperkingen. Desalniettemin kunnen de huidige bevindingen worden gezien als een bijdrage aan de literatuur die suggereert dat verhoging van fysieke activiteit inderdaad een effectieve behandeling kan zijn gericht op het verbeteren van cognitieve controle in risicopopulaties, zelfs bij een lichte intensiteit. Samenvattend hebben we vastgesteld dat interventies gebaseerd op fysieke activiteit effectief kunnen zijn in het verminderen van antisociaal gedrag op basis van eerdere studies (hoofdstuk 4). Vervolgens bevestigden we hoge niveaus van zelfgerapporteerde fysieke activiteit en verminderde cognitieve controle in deze steekproef van multi-probleem jongvolwassenen (hoofdstuk 5). En tot slot ontdekten we dat we zelfs binnen deze toch al relatief hoog-actieve groep we de cognitieve controle kunnen verbeteren met behulp van een 6 weekse bewegingsinterventie ingebed in een multimodaal dagbehandelingsprogramma (hoofdstuk 6), ongeacht de bewegingsintensiteit.

Voorbij fysieke activiteitsinterventies: persoonlijke ervaringen van multi-probleem jongvolwassenen

Onze resultaten, samen met eerdere studies, wijzen op de mogelijke voordelen van fysieke activiteit bij het verminderen van antisociaal gedrag. Veel van wat bekend is over deze potentiële voordelen komt uit kwantitatief onderzoek. Hoewel dit ons waardevolle inzichten verschaft, laat dergelijk onderzoek geen interpretatie toe van de subjectieve ervaring van fysieke activiteit. Er is eerder gesuggereerd dat niet de handeling van deelname zelf, maar eerder de ervaring de sleutel is tot het faciliteren van positieve gedragsresultaten (Coakley, 2011; Opstoel et al., 2019; Papacharisis et al., 2005). Daarom is het belangrijk om niet alleen te focussen op de kwantitatieve uitkomsten, maar ook om mogelijke kwalitatieve uitkomsten met betrekking tot fysieke activiteit te onderzoeken.

Om deze reden voerden we in hoofdstuk 7 een kwalitatief vervolgonderzoek uit met behulp van semigestructureerde interviews met jongvolwassenen met meerdere problemen (N = 15) waarin we hen interviewden over hun ervaringen met betrekking tot fysieke activiteit, de betekenis van fysieke activiteit, en hoe fysieke activiteit volgens hen een ondersteunende rol zou kunnen spelen bij hun problemen. Met behulp van een thematische benadering (Braun & Clarke, 2006) ontdekten we drie onderling gerelateerde thema's die mogelijk verklaren hoe fysieke activiteit kan bijdragen aan het stimuleren van positief gedrag en het verminderen van negatief gedrag. De drie thema's zijn: Dat fysieke activiteit als uitlaatklep kan dienen, persoonlijke ontwikkeling kan stimuleren en externaliserend gedrag kan verminderen, maar alleen als deelnemers zich veilig en gesteund voelen door de sportcoach.

Ondanks de toegenomen belangstelling voor lichaamsbeweging en sportprogramma's om de persoonlijke ontwikkeling van jongeren te stimuleren (Lumpkin, 2011; Makkai et al., 2003; Sandford et al., 2006) is er, voor zover de auteur weet, slechts beperkt kwalitatief onderzoek uitgevoerd onder jongeren of jongvolwassenen met een kwetsbare of complexe achtergrond (Haudenhuyse et al., 2013; Super et al., 2017b, 2017a). De huidige bevindingen komen grotendeels overeen met deze (beperkte) eerdere studies, wat aangeeft dat zowel kwetsbare jongeren (d.w.z. die het risico lopen om multi-probleem te worden) als multi-probleem jongvolwassenen (d.w.z. die lijden aan een overvloed aan problemen) mogelijk baat kunnen hebben van fysieke activiteit.

Conclusie

Het huidige proefschrift onderzocht het effect van fysieke activiteit op antisociaal gedrag en de mogelijke rol van cognitieve controle. Onze bevindingen suggereren dat, over het algemeen, verhoogde fysieke activiteit mogelijk kan worden gebruikt om antisociaal gedrag te verminderen bij (jong)volwassenen met antisociale gedragsproblemen. Daarnaast vonden we een associatie tussen een neurobiologische maat van cognitieve controle (ACC-activiteit tijdens responsinhibitie) en betere behandeluitkomsten (grotere kans om deel te nemen aan dagactiviteiten) in multi-probleem jongvolwassenen een jaar na deelname aan een multimodaal dagprogramma. Ook suggereren onze bevindingen een verbeterd neurocognitief functioneren na een volgen van een bewegingsinterventie bij jonge volwassenen met verminderde cognitieve controle die lijden aan meerdere problemen, waaronder agressie, delinquent gedrag, frequent middelengebruik en ander externaliserend gedrag. In navolging van eerdere onderzoeken, suggereren de resultaten van het huidige proefschrift twee belangrijke punten: (a) behandelingen en programma's die lichaamsbeweging omvatten, zijn mogelijk een makkelijk toepasbare behandeling voor antisociaal gedrag, en (b) dit gunstige effect op gedrag kan mogelijk deels worden toegeschreven aan een verbetering van cognitieve controle. Desondanks is aanvullend onderzoek nodig op deze hypothese nader te onderzoeken.

Implicaties en aanbevelingen toekomstig onderzoek

De huidige resultaten suggereren dat fysieke activiteit mogelijk kan dienen als een effectieve behandeling bij het verminderen van verschillende soorten antisociaal gedrag bij (jong)volwassenen die dit soort gedrag vertonen. Deze conclusie werd getrokken op basis van zowel kwantitatieve (hoofdstuk 4) als kwalitatieve (hoofdstuk 7) gegevens en komt overeen met eerdere onderzoeken bij kinderen en adolescenten (Harwood et al., 2017; Spruit et al., 2016), wat de algehele positieve effecten van fysieke activiteit op externaliserend en negatief gedrag aantonen. Dergelijke positieve resultaten moeten met de nodige voorzichtigheid worden geïnterpreteerd, aangezien de activiteit aan bepaalde randvoorwaarden moet voldoen, zoals het creëren van een veilige en stimulerende omgeving met een herkenbare coach. Soortgelijke conclusies worden getrokken in andere populaties, zoals in kwetsbare bevolkingsgroepen (Haudenhuyse et al., 2013; Super et al., 2017a, 2017b), wat aangeeft dat speciale aandacht moet worden besteed aan het hoe en waar van programma's voor lichaamsbeweging. Ondanks het groeiende bewijs van deze (overwegend) positieve effecten en de hoge zelfgerapporteerde fysieke activiteit van de multi-probleem jongvolwassenen, voldoen veel andere jongvolwassenen niet aan de globale gezondheidsrichtlijnen voor lichaamsbeweging (Marques et al., 2015; Song et al., 2013). De resultaten van dit proefschrift, in combinatie met eerdere studies, vragen om meer aandacht voor effectieve programma's om jonge volwassenen, met name degenen die antisociaal gedrag vertonen, aan te moedigen om deel te nemen aan fysieke activiteiten. Bovendien is het ook belangrijk om na te gaan hoe fysieke activiteit positieve gedragsveranderingen kan stimuleren, aangezien de onderliggende mechanismen (waaronder neurocognitief functioneren) complex zijn en meer onderzoek behoeven. Het blijft bijvoorbeeld onduidelijk of de verbetering van het gedrag na fysieke activiteit wordt beïnvloed door een verbetering van de executieve functies, aangezien dit niet is gemeten in het huidige proefschrift.

Daarnaast kan het waardevol zijn om te onderzoeken of andere populaties met verminderde neurocognitieve functies, zoals diegenen die lijden aan Attention Deficit/Hyperactivity Disorder (ADHD) of hersentrauma, ook baat kunnen hebben bij verhoogde fysieke activiteit (Varigonda et al., 2021). Op basis van dit proefschrift wordt aanbevolen om neuroimaging en gedragsmetingen te combineren om na te gaan of fysieke activiteit neurobiologische indicatoren van cognitieve controle kan beïnvloeden, zoals ACC-activiteit tijdens responsinhibitie, aangezien de huidige bevindingen wijzen op een direct verband tussen behandeluitkomst en ACC-activiteit gerelateerd aan responsinhibitie.

En tot slot, hoewel verminderde cognitieve controle is geassocieerd met antisociaal gedrag, is het nog niet duidelijk of verbeterde cognitieve controle ook zou kunnen leiden tot verminderd antisociaal gedrag. Uitgaande van een positief effect van fysieke activiteit op cognitieve controle, zou de volgende logische stap zijn om te onderzoeken of deze cognitieve controleverbetering zou kunnen leiden tot een vermindering van antisociaal gedrag, bijvoorbeeld door een follow-up uit te voeren waarin veranderingen in antisociaal gedrag worden gemeten. Idealiter zou dit een onderzoek zijn dat een bewegingsprogramma implementeert met ten minste twee groepen (bijvoorbeeld bewegen versus niet bewegen). Daarnaast zou het ook waardevol kunnen zijn om zowel sedentaire als zeer actieve deelnemers op te nemen en verschillende trainingsintensiteiten te gebruiken, aangezien onze steekproef van jongvolwassenen al relatief veel (zelfgerapporteerde) fysieke activiteit vertoonde. Dit zou kunnen vaststellen of er een mogelijke dosis-responsrelatie bestaat tussen fysieke activiteit en cognitieve controle. Andere aanbevelingen zijn om gebruik te maken van (bij voorkeur meerdere) geldige en robuuste instrumenten om fysieke activiteitsniveaus en -intensiteit te meten (bijv. VO2 max), een duidelijk oefenprotocol hebben (bijv. alleen wisselende intensiteit tussen verschillende groepen), alsook het inzetten van een coach aan wie de deelnemers kunnen relateren (bijvoorbeeld op basis van een gedeelde culturele achtergrond).

Dankwoord

Beste collega’s, vrienden, familie,

Allereerst wil ik alle deelnemers bij De Nieuwe Kans bedanken. Dit proefschrift is voor en door jullie tot stand gekomen en ik hoop oprecht dat de resultaten van dit onderzoek (al is het maar een heel klein beetje) gebruikt kunnen worden om jongeren zoals jullie te helpen.

Ook wil ik de medewerkers van De Nieuwe Kans bedanken, niet alleen voor het introduceren van een extra sportles speciaal voor dit onderzoek, het inrichten van een kantoortje voor mij en mijn studenten, of voor jullie assistentie bij het motiveren van de jongens, maar vooral ook omdat het altijd enorm duidelijk was dat jullie hart bij het helpen van de jongeren lag.

Bedankt aan Reclassering Nederland en de Arnold Oosterbaan Hersenstichting voor het financieren van dit onderzoek en de vrijheid die ik kreeg om dit project in te richten en uit te voeren.

Reshmi, dankjewel voor de ontelbare keren dat je (soms ook ’s nachts) naar mijn stukken hebt gekeken of dat je ondanks je vrije dagen toch bij de moeilijk te plannen overleggen met de promotoren aanwezig was. Van jou kreeg ik de gouden tip over hoe ik met ongemotiveerde studenten moet omgaan, namelijk: niet ervan uitgaan dat iedereen zo'n passie heeft voor onderzoek. Dat advies pas ik ook in het dagelijkse leven nog erg vaak toe, dus bedankt hiervoor.

Erik, ik ben jou heel erg dankbaar voor alle jaren goede begeleiding, je vertrouwen en je eindeloze enthousiasme voor bewegen en hersenen. Al voor mijn proefschrift inspireerde je mij met jouw passie voor dit onderwerp, zowel in de collegezalen als in het trappenhuis van het hoofdgebouw als we samen naar de 15^{e} verdieping liepen (jij met een stevige trend voorop, en ik puffend achter je aan). Ik ben dan ook erg blij dat je (toch wel) tot het einde mijn eerste promotor bent gebleven.

Peter, bedankt voor jouw onmisbare expertise vanuit het criminologische veld. Door jouw inzet en begeleiding kon ik vol vertrouwen beginnen aan dit topic, ook al was het voorheen compleet nieuw terrein voor mij. Het dwong mij ook om soms kritisch na te denken over dingen die vanuit neuropsychologie misschien vanzelfsprekend leken, maar vanuit andere werkvelden een stuk minder logisch waren.

Arne, ook jij bedankt voor je waardevolle feedback en inzet. Met jou, Peter en Erik als mijn promotoren had ik een overvloed aan kennis tot mijn beschikking waardoor ik mijzelf en mijn werk enorm heb kunnen ontwikkelen.

Nanda, zonder jou zou ik (letterlijk) nooit aan een promotietraject zijn begonnen. Jouw vertrouwen in mij als jouw student-assistent en als persoon zorgden ervoor dat ik zeker genoeg werd van mijn zaak om te willen promoveren. Jij was ook degene die mij als eerste op de sollicitatie wees en heeft geholpen met de voorbereiding. Ik vind het dan ook heel fijn dat je ook nu tijdens de afronding aan mijn zijde staat als mijn paranimf.

Bedankt Josjan, omdat je nooit te beroerd was om op mijn appjes of mails te reageren als ik weer eens compleet vastliep (vaak in statistiek). Jouw suggesties op mijn stukken tekst hielpen daarnaast heel erg met het inbinden en verbeteren van dit proefschrift. Van jou heb ik geleerd om altijd bewust te zijn van de bronnen van mijn uitspraken.

Winston, Damian, bedankt voor jullie medewerking en eindeloze motivatie om te sporten met de jongens. Jullie enthousiasme voor het vak en voor de doelgroep zorgden ervoor dat zelfs de meest ongemotiveerde deelnemers toch met (enig) plezier naar de sportlessen kwamen.

Bedankt ook aan alle stagiaires, bachelorstudenten en masterstudenten. Dit topic vroeg soms veel van jullie zoals lange reistijd, omgaan met teleurstellingen en werken in de avond, maar vaak deden jullie dit zonder te klagen. Zonder jullie hulp was er niet genoeg data geweest om een proefschrift over te schrijven, dus dank jullie wel voor jullie inzet!

Juna, Merel, Marjolein; Dank jullie wel alle keren dat ik kon klagen over mijn proefschrift en alle leuke uitstapjes samen. Ook heel erg bedankt voor alle lieve appjes en kaartjes die jullie blijven sturen ook al ben ik soms enorm traag met reageren. Weet dat ik ze altijd lees en waardeer. Merel, extra bedankt voor jouw goede ondersteuning als mijn paranimf en vooral ook voor de enorme taak van spellingscheck op dit proefschrift (waardoor er toch een vrij cruciale fout uit de header is opgelost).

Tessa, bedankt voor de vele, vele jaren dat we vriendinnen zijn en alles wat we al samen hebben beleefd. We zien elkaar misschien niet meer zo vaak maar ik waardeer onze vriendschap enorm. Je was er toen ik je nodig had, weet dat ik er ook voor jou ben als je mij nodig hebt.

Rob, nerd, thanks dat je blijft checken hoe het met me gaat ondanks je inmiddels drukke burgerlijke leven. Ik ben blij dat ik alles met je kan bespreken zonder dat je een oordeel velt, ook al zijn onze gespreksonderwerpen tegenwoordig (gelukkig) steeds vaker van het huisje-boompje-beestje niveau.

Vincent, mijn lieve niet meer zo kleine broertje. Ik ben zo ontzettend trots op de man die je bent geworden. Ik kon alleen maar studeren en later promoveren omdat ik wist dat jij (ook al was het misschien niet altijd compleet vrijwillig) het thuisfront bleef bewaken. Weet dat je altijd langs mag komen voor een praatje. Ik heb geen dvd's, maar ik kan wel soto maken.

Lieve mamma, wat hebben we toch veel meegemaakt de afgelopen periode. Woorden kunnen niet beschrijven hoe dankbaar ik ben dat we in ieder geval elkaar nog hebben. Dankzij jouw steun kon ik dit proefschrift ondanks alles toch succesvol afronden. Door jou ben ik de persoon geworde die ik vandaag ben. Ik wil jou en Vincent allebei bedanken voor jullie onvoorwaardelijke liefde en vertrouwen, zonder jullie was ik nooit zo ver gekomen in mijn carrière.

En als laatste mijn beste vriend en lieve verloofde, Ivo. Bedankt voor alle kopjes thee, schoudermassages, potjes Wildrift, crypto-colleges, wandelrondjes, spijbeluurtjes Zelda, en boodschappentripjes, waardoor ik weer genoeg opgepept was om toch nog een paar uur verder te schrijven. Ook bedankt dat je naar mijn eindeloze geklaag hebt geluisterd en dat je altijd klaar stond met een oplossing voor mijn problemen. Bedankt voor al het begrip en steun toen ik het het hardst nodig had. Bedankt ook dat je mij hebt aangemoedigd om toch de stap naar data analytics te maken en dat je altijd in mij hebt geloofd. Met jou aan mijn zijde kan ik alles.

Curriculum vitae

Maria-Elise was born in Nijmegen, on September 7th, 1991. After the completion of her secondary education (VWO) at the Pax Christi College in Druten, she obtained a Bachelor's degree in Sociology at the University of Amsterdam in 2014 and a Bachelor's degree in Psychology at the Tilburg University in 2016. She continued with a master in Clinical Neuropsychology at the Vrije Universiteit Amsterdam, which she finished in 2018. From September 2016 to April 2018 she also worked as a research assistant for dr. Nanda de Knegt at the faculty of Behavioural and Movement Sciences, department Clinical, Neuro- and Developmental Psychology, section Neuropsychology at the Vrije Universiteit. In April 2018 she was able to start her PhD on physical activity, cognitive control, and antisocial behavior at the same section under the supervision of promoters prof.dr. Erik Scherder, prof.dr. Peter van der Laan, prof.dr. Arne Popma and copromotor dr. Reshmi Marhe. During her PhD, she participated in several post-graduate courses at the Vrije Universiteit Amsterdam and supervised research projects of multiple bachelor and master students. In August 2023 she started a traineeship Business Analytics and Data Science at Breinstein, given in collaboration with Vrije Universiteit Amsterdam and Data Science Alkmaar.