Neuropsychologia 99 (2017) 172–178

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

# Deficits in inhibitory force control in young adults with ADHD

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A R T I C L E I N F O

*Keywords:*
Grip force
Motor control
Attention-deficit/hyperactivity disorder (ADHD)
Response inhibition
Go/no-go task

A B S T R A C T

Poor inhibitory control is a well-established cognitive correlate of adults with ADHD. However, the simple reaction time (RT) task used in a majority of studies records performance errors only via the presence or absence of a single key press. This all-or-nothing response makes it impossible to capture subtle differences in underlying processes that shape performance. Subsequently, all-or-nothing tasks may underestimate the prevalence of executive function deficits in ADHD. The current study measured inhibitory control using a standard Go/No-Go RT task and a more sensitive continuous grip force task among adults with (N = 51, 22 female) and without (N = 51, 29 female) ADHD. Compared to adults without ADHD, adults with ADHD made more failed inhibits in the classic Go/No-Go paradigm and produced greater and more variable force during motor inhibition. The amount of force produced on failed inhibits was a stronger predictor of ADHD-related symptoms than the number of commissions in the standard RT task. Adults with ADHD did not differ from those without ADHD on the mean force and variability of force produced in Go trials. These findings suggest that the use of a precise and continuous motor task, such as the force task used here, provides additional information about the nature of inhibitory motor control in adults with ADHD.

## 1. Introduction

Attention deficit hyperactivity disorder (ADHD) is a common childhood-onset disorder characterized by age-inappropriate, chronic, pervasive, and impairing levels of inattention and/or hyperactivity-impulsivity (American Psychiatric Association 2013). ADHD persists into adulthood in up to 65% of cases (Faraone et al., 2006; Simon et al., 2009; Turgay et al., 2012), affects the ability to gain and maintain employment (Kessler et al., 2009; Kupper et al., 2012), and is associated with an increased risk for substance abuse (Wilens et al., 1995; Upadhyaya, 2008; Groenman et al., 2013), obesity (Cortese et al., 2008; Nazar et al., 2012, 2014; Albayrak et al., 2013), workplace injuries (Swensen et al., 2004; Breslin and Pole, 2009; Hodgkins et al., 2011), and traffic accidents (Barkley et al., 1993; Jerome et al., 2006a, 2006b; Barkley and Cox, 2007; Merkel et al., 2013). Though less often discussed, motor impairments are prominent among children with ADHD (Barkley, 1998) and up to 50% of pediatric ADHD patients are also comorbid for developmental coordination disorder (Kadesjo and Gillberg, 1999; Pitcher et al., 2003; Gillberg et al., 2004). Similarly, adults with ADHD have impaired visuomotor memory in gripping tasks (Neely et al., 2016), visuomotor adaptation in reaching tasks (Kurdziel et al., 2015), deficits in oculomotor control (Feifel et al., 2004; Carr et al., 2006), increased postural sway (Hove et al., 2015), and impaired timing in finger tapping tasks (Valera et al., 2010). These findings are important because motor processes have clearer neural correlates than many of the cognitive constructs associated with ADHD. Thus, the motor system provides a good avenue to examine the neurobiology of ADHD.

Inhibitory control is the process of suppressing competing responses to select the most appropriate response. The ability to suppress inappropriate behaviors in favor of appropriate alternatives is paramount to adapting behavior in changing circumstances and is thereby a critical component for controlling behavior at all levels, including movement. Although numerous studies report poor inhibitory control in ADHD (Nigg et al., 2002; Aron and Poldrack, 2005; Alderson et al., 2007; Wodka et al., 2007; Suskauer et al., 2008; Gilbert et al., 2011; Bari and Robbins, 2013)**,** the type of task used in the majority of studies (e.g. go-no-go or stop signal reaction time, RT, task) records performance via the presence or absence of an all-or-nothing key press. Such an approach confounds cognitive, sensory, and motor processes into a single dichotomous response. As a result, we may be overlooking critical processes that provide insight into the neural mechanisms of

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http://dx.doi.org/10.1016/j.neuropsychologia.2017.03.012
Received 10 December 2016; Received in revised form 6 March 2017; Accepted 8 March 2017
Available online 09 March 2017
0028-3932/ 

the disorder. For example, a great deal of motor activity can be produced even when an individual does not ultimately press a key in a standard RT task. The current study overcomes this barrier by using a continuous and precise measure of motor output in a grip force variant of the classic go/no-go task. We used force output as a measure of activity in the motor system. In order to test the validity of this measure, participants completed a continuous grip force go/no-go task with both low and high force amplitude conditions as well as a standard go/no-go task that used an all-or-nothing keypress. Trials were presented rapidly, creating a prepotency to respond. In this context, the inhibition of a prepotent response requires effortful cognitive control, whereas allowing the motor response to proceed occurs in a more automatic fashion (Bargh et al., 1996; Muraven and Baumeister, 2000). We reasoned that greater activity in the motor system would be reflected by the production of larger forces during no-go trials. We included low and high force amplitude conditions as a means to examine response planning. In particular, the amount of force produced on a no-go trial may reflect a pre-planned response and scale to the target amplitude. Therefore, deficits in response planning would be indicated by force output (on no-go trials) that does not scale to the target amplitude.

## 2. Methods

### 2.1. Participants

We recruited young adults, ages 18–25, who identified as currently having ADHD or as having never been diagnosed with ADHD. Participants were community recruited through advertisements in State College, Pennsylvania. Exclusion criteria included: (1) previous concussions that resulted in a loss of consciousness for more than 10 min; (2) previous diagnosis of seizures, epilepsy, encephalitis, meningitis or an autism spectrum disorder; (3) previous diagnosis of a musculoskeletal or neurological disorder; and (4) previous diagnosis of any disorder involving psychosis.

#### 2.1.1. Adults with ADHD

Adults with ADHD met DSM-V criteria including cross situational severity and impairment as determined by a semi-structured interview, the Conners' Adult ADHD Diagnostic Interview (CAADID; Multi-Health Systems Inc.). Adults had $\geq$5 symptoms of inattention or hyperactivity, that were impairing in at least two settings (e.g. family and work). In total, 53 young adults met the criteria for ADHD. However, two participants did not complete the go/no-go task as instructed. These individuals were unable to keep pace with the speeded trial presentation in the motor task. The final ADHD group (N = 51, 29 females) had a mean age of 21.10 $\pm$ 1.71 years. Adults taking a psychostimulant (N = 22) completed the laboratory session after a 24-h washout period. No participants were taking medications known to affect motor control at the time of testing, including antipsychotics, stimulants, or anticonvulsants (Reilly et al., 2008).

#### 2.1.2. Adults without ADHD

Age- and sex- matched controls reported < 3 total symptoms and $\leq$2 symptoms per ADHD dimension. Self-report of anxiety and/or depression was not exclusionary. A total of 73 young adults met the criteria for healthy control. The included participants (N = 51, 22 females, 21.00 $\pm$ 1.70 years) were chosen as age- and sex-matched controls for the ADHD group.

### 2.2. Procedures

The experimental task was completed as part of a larger battery of experimental and standardized measures that took place in one 3-h session. After a complete description of the study, written informed consent was obtained from the participant. All procedures were approved by the Institutional Review Board at The Pennsylvania State University, and were consistent with the Declaration of Helsinki. All participants received monetary compensation for their participation in the study.

In advance of the laboratory session, all participants completed a brief medical history, the long form of the Connors Adult ADHD Rating Scales (CAARS), the Achenbach Adult Self Report (ASR) (Achenbach, 2003), and the Edinburgh Handedness Inventory (Newcombe et al., 1971). Symptoms of ADHD were assessed with the self-report, long version (S: L) of the CAARS, which has 66 items and 8 factor-derived subscales: Inattention/Memory Problems, Hyperactivity/Restlessness, Impulsivity/Emotional Lability, Problems with Self-Concept, DSM-IV Inattentive Symptoms, DSM-IV Hyperactive/Impulsive Symptoms, DSM-IV ADHD Symptoms Total, and an ADHD Index. Symptoms of conditions that commonly co-occur with ADHD (e.g. anxiety, depression, and conduct problems) were evaluated with the ASR, a 123-item rating scale scored with a 3-point Lickert scale. The ASR has excellent psychometric properties and uses age-based normative data to identify normal, borderline clinical, and clinical ranges of behavior (Achenbach, 2003). Handedness was assessed with the Edinburgh Handedness Inventory (Muth et al., 1971). The 10-item inventory asks participants to indicate which hand they would use to complete common tasks, such as striking a match, throwing, or using scissors. Handedness is determined using a laterality quotient ($LQ = (r\text{-}L)/(R + L)*100$), where a score of 100 reflected complete right-hand dominance, and a score of −100 reflected complete left-hand dominance.

In the laboratory session, participants completed a semi-structured interview, the CAADID, which was updated to reflect the criteria of the DSM-5. Other tests conducted during the lab visit included portions of the Wechsler Adult Intelligence Scale-Fourth Edition (WAIS-IV) (Wechsler, 2008) to estimate intelligence quotient (IQ), the Purdue Pegboard Test (Buddenberg and Davis, 2000) to assess coordination, and dynamometer tests for maximum pinch grip strength.

#### 2.2.1. Go/No-Go force task

Stimuli were presented on a 102 cm Samsung television screen with 1920 × 1080 resolution and 120 Hz refresh rate. Participants were comfortably seated in a chair (JedMed Straight Back Chair, St. Louis, MO) facing the center of the TV screen a horizontal distance of 127 cm. Their dominant arm rested at approximately 100 degrees of flexion on a height-adjustable table. As shown in Fig. 1A, participants used their thumb and index finger to form a pinch grip against a custom-built force apparatus with identical button load cells on either side (Measurement Specialties, Hampton, VA). Total force produced by the thumb and index finger was measured. Voltage outputs were sent to a transducer coupler to be amplified (Coulbourn Instruments Type B V72-25B), transmitted via a 16-bit A/D converter, and digitized at 62.5 Hz. Digitized voltage signals were transformed to Newtons with a resolution of .0016 N. The summed force output from the load cells was presented on the television screen in real time. Voltage data acquisition, voltage-to-force transformation, and stimuli presentation were all conducted using customized programs written in LabVIEW (National Instruments, Austin, TX).

Before the force task, each participant's maximum voluntary contraction (MVC) was measured using a pinch grip dynamometer (Lafayette Hydraulic Pinch Gauge, Model J00111, Lafayette, IN). The average of three, five-second trials determined each participant's maximum voluntary contraction (MVC) in Newtons. MVC was then used to create target force amplitudes for each participant. During the experiment, the visual display consisted of two rectangular bars on a black background (Fig. 1C). A stationary, white target bar represented the target force. For each run, the target was normalized to 15% (low amplitude) or 60% (high amplitude) of the participant's MVC. A second colored bar moved up with increasing applied force and down with decreasing force. The distance moved by this bar was proportional to the amount of force produced. When no force was produced, the