Research in Developmental Disabilities 32 (2011) 1011–1020

Contents lists available at ScienceDirect

Research in Developmental Disabilities

Atypical acquisition and atypical expression of memory consolidation gains in a motor skill in young female adults with ADHD

Esther Adi-Japha [a,*], Orly Fox [b,c], Avi Karni [b]

[a] School of Education and the Leslie and Susan Gonda (Goldschmied) Multidisciplinary Brain Research Center, Bar-Ilan University, Ramat-Gan 52900, Israel
[b] Dept. of Human Biology and the Edmond J. Safra Brain Research Center for the Study of Learning Disabilities, University of Haifa, Israel
[c] The Zinman College of Physical Education and Sport Sciences at the Wingate Institute, Israel

ARTICLE INFO

Article history:
Received 11 March 2010
Received in revised form 24 January 2011
Accepted 25 January 2011
Available online 23 February 2011

Keywords:
ADHD
Motor learning
Procedural memory consolidation
Speed-accuracy trade-off

ABSTRACT

Individuals with ADHD often show performance deficits in motor tasks. It is not clear, however, whether this reflects less effective acquisition of skill (procedural knowledge), or deficient consolidation into long-term memory, in ADHD. The aim of the study was to compare the acquisition of skilled motor performance, the expression of delayed – consolidation phase – gains and retention, in persons with and without ADHD. Thirty-two participants, 16 with ADHD, were trained on a sequence of finger movements using a well-established training protocol, and tested before training and immediately, 24 h and 2 weeks after training. Both groups showed similar within-session gains in speed; additional, delayed gains were expressed at 24 h, but less robustly in ADHD, and at 2 weeks post-training. However, while controls showed significant delayed gains in accuracy at 24 h and 2 weeks post-training, accuracy deteriorated in ADHD from pre-training to 24 h post-training and was only at pre-training levels by 2-weeks post-training. Our results demonstrate a latent memory consolidation phase in motor sequence learning, expressed as delayed gains in speed and a much delayed recovery of pre-training accuracy, in individuals with ADHD. However, both the acquisition and memory consolidation of motor skills are atypical in ADHD.

1. Introduction

The core symptoms of Attention Deficit Hyperactivity Disorder (ADHD) in children are inattention, impulsivity and hyperactivity (APA, 2000). These symptoms are often associated with impaired cognitive academic performance (Loe & Feldman, 2007). However, additional concerns have been raised by evidence of difficulties in skilled motor performance in these children (Eliasson, Rosblad, & Forssberg, 2004; Harvey & Reid, 2003; Mostofsky et al., 2006; Pitcher, Piek, & Hay, 2003; Sheppard, Bradshaw, Georgiou, Bradshaw, & Lee, 2000). For example, deficits in tasks such as buttoning up, tying shoe laces and writing or printing letters were described (Adi-Japha et al., 2007; Karatekin, Markiewicz, & Siegel, 2003). Children with ADHD are often impaired in the performance of repetitive motor tasks (Barnes, Howard, Howard, Kenealy, & Vaidya, 2010; Mostofsky et al., 2006) and these impairments were taken as evidence for procedural memory deficits (Barnes et al., 2010). The term – procedural memory – refers to the long-term memory system subserving the acquisition and retention of skills ('how to' knowledge) and habits, specifically, the repetition dependent, implicit, knowledge of the structure of recurring experiences (Brown & Robertson, 2007; Cohen & Squire, 1980; Karni, 1996; Squire, 1992). Klorman et al. (2002) reported

* Corresponding author. Tel.: +972 3 5318704; fax: +972 3 6354997.
E-mail addresses: japhae@mail.biu.ac.il, Esther.Japha@gmail.com (E. Adi-Japha).

0891-4222/$ – see front matter
doi:10.1016/j.ridd.2011.01.048

that children with ADHD were less sensitive to violations of regularity in short stimulus sequences compared to their peers. It has been suggested that skill acquisition is hampered in children with ADHD due to a deficit in sustaining attention resources (Burden & Mitchell, 2005), and that these children demonstrate impaired or immature automatic inhibition of unintentional movements during repetitive tasks (Denckla, 1985; Mostofsky, Newschaffer, & Denckla, 2003). Furthermore, it was recently proposed that deficits in generating procedural memory may constitute a core deficit in ADHD (Nicolson & Fawcett, 2007).

Nevertheless, while there is some evidence in support of the notion of impaired skill acquisition in individuals with ADHD (Aman, Roberts, & Pennington, 1998; but see Karatekin, White, & Bingham, 2009; Karatekin et al., 2003; Klorman et al., 2002; Kopecky, Klorman, Chang, Thatcher, & Borgstedt, 2005; Mostofsky et al., 2006; Silk et al., 2005), there is no direct evidence that the learning curves of individuals with ADHD deviate from the expected. In most studies, a pre-training deficit (reflected in the initial performance of the trained task) was found for the participants with ADHD, suggesting a deficit in performance rather than in learning *per se*. Indeed, Mostofsky et al. (2006) reported comparable gains in performance speed on simple movement sequences in individuals with and without ADHD given an equal amount of practice. In some cases, however, the deficit was restricted to accuracy of performance in ADHD. For example, Silk et al. (2005) found adolescents with ADHD to be less accurate (although equally fast) than controls in the mental rotation task.

Follow-up studies show that up to 60% of children with ADHD continue to show all or some of the ADHD characteristics as adults (Barkley, 2002; Biederman et al., 2008; Davidson, 2008; Kooij et al., 2010; Polanczyk & Rohde, 2007; Schneider et al., 2010). It is not clear, however, if and in what manner adults with ADHD are impaired in their ability to acquire new motor skills and to retain them in long-term memory. In the current study the changes in performance, speed and accuracy, induced by a single session of training on a finger opposition sequence (FOS) learning task were studied in young female adults with ADHD.

The FOS task consists of a 5-element sequence of finger-to-thumb opposition movements. The sequence is explicitly introduced to the participants before the first recorded trial. Performance gains reflect increased skill of execution (Karni et al., 1995, 1998; Korman, Raz, Flash, & Karni, 2003; Maquet et al., 2003). Sequential finger movement tasks have been used to study abnormalities in motor performance in individuals with ADHD (Mostofsky et al., 2006), as well as to study the behavioral and brain mechanisms associated with the establishment of long-term procedural memory (Debas et al., 2010; Dorfberger, Adi-Japha, & Karni, 2007; Fischer, Hallschmid, Elsner, & Born, 2002; Karni et al., 1995, 1998; Korman et al., 2003, 2007; Toni, Krams, Turner, & Passingham, 1998; Walker, Brakefield, Morgan, Hobso, & Stickgold, 2002; Walker, Stickgold, Alsop, Gaab, & Schlaug, 2005). ADHD has frequently been related to abnormalities in the frontal–striatal or frontal–cerebellar circuits (Singh, 2008), circuits involved in learning new skills (Debas et al., 2010; Robertson, Pascual-Leone, & Miall, 2004).

It was previously shown in a number of perceptual and motor skill learning paradigms, including the FOS task, that in typically developing children as well as in adults, the evolution of long term memory for skilled performance can be characterized by several distinct phases (Adi-Japha, Karni, Parnes, Loewenschuss, & Vakil, 2008; Ari-Even Roth, Kishon-Rabin, Hildesheimer, & Karni, 2005; Dorfberger et al., 2007; Fischer et al., 2002; Hauptman, Reinhart, Brandt, & Karni, 2005; Hauptmann & Karni, 2002; Karni & Sagi, 1993; Karni et al., 1995, 1998; Korman et al., 2003, 2007; Walker et al., 2005). Characteristically, large gains in performance speed, with no loss of accuracy, occur early in the initial training session (fast learning, ‘‘novelty’’, phase) (Karni & Sagi, 1993; Korman et al., 2003). This phase of rapid improvement in performance is followed, if the training session is continued, by a second (plateau) phase wherein performance in terms of both speed and accuracy asymptotes. Additional robust gains in performance can be expressed hours after the termination of training, for example by 24 h post-training. It was proposed that these delayed (between-sessions, ‘‘offline’’) gains in performance, in speed as well as accuracy, reflect latent neuronal long-term memory consolidation processes (consolidation phase). These consolidation processes are triggered by task repetitions during the training session, but require time, and often sleep, to reach completion (Fischer et al., 2002; Karni et al., 1998; Korman et al., 2003, 2007; Maquet et al., 2003; Walker et al., 2002, 2005). In some cases additional gains were recorded beyond the first 24 h post training (Dorfberger et al., 2007; Korman et al., 2003). The performance level attained after the completion of the consolidation phase can be well retained for weeks and months (Dorfberger et al., 2007; Karni, 1996; Korman et al., 2003). If, however, the training session is terminated before the plateau phase is attained (as may be the case for ineffective learning) consolidation phase gains may not occur (Hauptman et al., 2005; Hauptmann & Karni, 2002; Karni, 1996).

The current experiment was designed to study the time-course of learning a motor skill, the FOS task, in young adults with ADHD. Due to gender differences reported in studies of skilled movements in ADHD (Cole et al., 2008; Kadesjo et al., 2004), the current sample included only female participants (see further details in Section 2). To this end, speed and accuracy of performance before and immediately after the training experience (within-session gains), the evolution of delayed performance gains (between-session, consolidation phase gains) and retention at 2 weeks post-training were studied in individuals with ADHD and in a control group without ADHD. It was hypothesized that due to their difficulty in allocating attention resources to repetitive experiences (Burden & Mitchell, 2005) and due to their difficulty in controlling unintentional movement on repetitive finger tasks (Denckla, 1985; Mostofsky et al., 2003, 2006), individuals with ADHD would show deficient learning, characterized by a slower improvement in speed and a lower accuracy.