

# Attentional Requirements During Acquisition and Consolidation of a Skill in Normal Readers and Developmental Dyslexics

Yafit Gabay, Rachel Schiff, and Eli Vakil  
Bar-Ilan University

**Objective:** Previous research demonstrated that individuals with developmental dyslexia (DD) may suffer from a deficit in the acquisition stage of a new skill, whereas consolidation processes seem to be preserved. The present study was designed to examine whether this impaired acquisition was attributable to a lack of automatization, and whether the reported preserved consolidation was attributable to the use of DDs' conscious compensation strategies. These aims were implemented by testing a skill-learning task in dyslexics and normal readers using a dual task paradigm. The impact of dual task costs on participants' performance was used as an indication for automaticity. **Method:** DD and control groups completed a sequence-learning task over a first session (acquisition) and a second session 24 hours later (consolidation). The task was performed by half of the participants under a full attention condition and by the other half under a divided attention condition. **Results:** Consistent with previous reports in the literature, divided attention impaired sequence learning in both groups. Nevertheless, divided attention resulted in delayed acquisition of the motor skill in the DD group compared with normal readers. Finally, divided attention enhanced motor procedural consolidation only in the control group. **Conclusions:** The differential effect of divided attention on acquisition and consolidation of procedural skill in DD and normal readers supports the cerebellum deficit hypothesis in DD. In addition, the enhanced skill consolidation in normal readers under divided attention suggests that attentional requirements are not necessary for all types of human learning.

**Keywords:** developmental dyslexia, procedural learning, memory consolidation, dual task paradigm, automaticity

Developmental dyslexia (DD) is defined as a specific functional failure to acquire age-appropriate reading skills in otherwise normally developing children (Curtin, Manis, & Seidenberg, 2001; Stanovich, 1988; Vellutino, 1979). Despite decades of extensive research, the cognitive and biological mechanisms that underlie DD remain a controversial issue in the literature (for recent review, see Ramus & Ahissar, 2012). *The Phonological Deficit Hypothesis* (Snowling, 2000) implicates a deficit of direct access to, and manipulation of, phonemic language units retrieved from the long-term declarative memory. This framework was verified by numerous studies that indicated a phonological deficit in DD (Vellutino, Fletcher, Snowling, & Scanlon, 2004). Nevertheless, individuals with DD might exhibit deficits that are not restricted to the language domain. For example, individuals with DD were found to be

impaired in visual and auditory processing (Stein & Walsh, 1997), spatial attention (Facoetti, Lorusso, et al., 2003), information processing speed (Wolf & Bowers, 1999), and motor skills (Fawcett & Nicolson, 1995). These additional deficits have led researchers to search for a general explanatory framework that could account for the diversity of deficits in individuals with DD (Ahissar, 2007; Farmer & Klein, 1995; Hari & Renvall, 2001; Nicolson & Fawcett, 1990; Stein & Walsh, 1997).

One of these broader frameworks attempts to explain DD in terms of perceptual deficits which in turn lead to substantial difficulties in reading (the *Magnocellular Theory*; Stein & Walsh, 1997). This account is based on the observation that there are two visual pathways leading information from the eyes to the visual cortex (magnocellular/parvocellular systems). According to the *Magnocellular Theory*, the magnocellular pathway is selectively disrupted in individuals with DD, leading to visual/auditory perceptual deficits as well as difficulties in visuospatial attention via the posterior parietal cortex (e.g., Vidyasagar, 1999). Support for this account comes from studies which demonstrated impaired performance of individuals with DD on a variety of tasks which tap magnocellular functions (for reviews, see Laycock & Crewther, 2008; Stein, 2001), as well as from studies which demonstrated a direct link between reading and magnocellular dorsal stream measures (Kevan & Pammer, 2009). Nevertheless, the validity of this account is still hotly debated, mainly because of nonspecific or irreducible findings (Amitay, Ben-Yehudah, Banai, & Ahissar, 2002; Stuart, McAnally, & Castles, 2001).

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Yafit Gabay and Rachel Schiff, School of Education and Haddad Center for Research in Dyslexia and Learning Disabilities, Bar-Ilan University, Ramat-Gan, Israel; Eli Vakil, Psychology Department and the Leslie and Susan Gonda (Goldschmied) Multidisciplinary Brain Research Center, Bar-Ilan University.

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Correspondence concerning this article should be addressed to Yafit Gabay, School of Education and Haddad Center for Research in Dyslexia and Learning Disabilities, Bar-Ilan University, Ramat-Gan, Israel. E-mail: yafitvha@gmail.com

The viewpoint of impaired attention in DD has also been promoted by Hari and colleagues (the *Sluggish Attentional Shifting* account; Hari & Renvall, 2001). According to this approach, individuals with DD may suffer from sluggish attention deployment attributable to a right parietal lobe dysfunction. Indeed, previous research demonstrates DD individuals distribute attentional resources more diffusely (Facoetti, Paganoni, Turatto, Marzola, & Mascetti, 2000; Facoetti, Ruffino, Peru, Paganoni, & Chelazzi, 2008; Facoetti et al., 2010) and present slower capture of attention (Facoetti, Luisa Lorusso, Paganoni, Umiltà, & Gastone Mascetti, 2003), but once their attention is engaged it cannot easily be disengaged (Hari, Valta, & Uutela, 1999). Those attention problems seemed to be linked directly to DDs' reading deficits (Franceschini, Gori, Ruffino, Pedrolli, & Facoetti, 2012) and were found to be critical (in addition to reading functions) for DD management and identification (Facoetti et al., 2010). Recently, it was demonstrated that simple attentional manipulation (reducing crowding by extralarge spacing of letters) had a positive effect on DDs' reading (Zorzi et al., 2012), further supporting the importance of attention in DD etiology.

Although attentional problems in DD are well documented in the literature, the precise nature of the attentional deficits in DD remains debatable. Several researchers claim a mechanism of increased diffusivity of attention in DD (Facoetti & Molteni, 2001), but others favor the reduced visual attentional resources account (Bosse, Tainturier, & Valdois, 2007). In addition, several studies argued for a serial attention deficit (Vidyasagar & Pammer, 1999), whereas others proposed parallel attention deficit in DD (Lassus-Sangosse, N'guyen-Morel, & Valdois, 2008). Finally, the question of which component of attention is impaired in DD remains controversial as well. Posner and Petersen (1989) indicated the possible existence of three different attentional networks in the brain, each one differing in brain location and functions: the orienting, alertness, and executive control systems. Whereas a number of studies have demonstrated a deficit in orienting of attention in DD (Buchholz & Davies, 2005; Facoetti, Lorusso, et al., 2003; Ruffino et al., 2010), others indicated impairment in executive functions and cognitive control (Bednarek et al., 2004; Brosnan et al., 2002; Kapoula et al., 2010; Poljac et al., 2010; Reiter, Tucha, & Lange, 2005). To complicate things further, it is also possible that impairment in automatization processes might contribute further to the attentional problems that have been observed in DD. If simple basic skills are not automatized, they necessarily place greater demands on attentional resources, which may lead in turn to deteriorated performance.

The notion that DD might be linked to deficits in automatization processes was originally proposed in Nicolson and Fawcett's *Automaticity Deficit Hypothesis* (Nicolson & Fawcett, 1990), which was later modified to the *Cerebellum Deficit Hypothesis* (Nicolson, Fawcett, & Dean, 2001). Based on extensive longitudinal, behavioral, and anatomical studies (Nicolson & Fawcett, 1994a, 2000; Nicolson et al., 1999) it was claimed that individuals with DD may suffer from inability to automatize new procedural skills. The brain-level candidate that has been suggested to underlie the cognitive automatization deficit was the cerebellum, leading to difficulties in the acquisition and automatizing of cognitive and motor skills (but for recent broader brain network consideration, see Nicolson & Fawcett, 2011). According to this framework, for most skills, individuals with DD learn to mask their incomplete

automatization by a process of 'conscious compensation,' thereby achieving apparently near-normal performance, at the expense of greater effort (the *Conscious Compensation Hypothesis*; Nicolson & Fawcett, 1994a). However, once these conscious compensatory strategies are blocked by increasing task difficulty, the true deficits in automatization can be revealed. Although automaticity is well understood as a theoretical concept, its measurement is still a controversial issue in the field of psychology. By trying to operationalize this slippery concept, Nicolson and Fawcett (2008) suggest that characteristics of automatic performance may be seen as the *quality* of performance (speed and accuracy), *effortlessness* (low input of conscious resources), and *strength* of automatization (resistance to interference and to unlearning). According to this framework, automatization deficits in DD manifest in these parameters. Behavioral work supporting this account attempts to examine individuals with DD on a variety of procedural skills (for a review, see Folia et al., 2008). Additional studies manipulate attentional allocation during motor skills to unravel the core deficits in individuals with DD (Nicolson & Fawcett, 1990; Yap & van der Leij, 1994). Before introducing studies of procedural learning in DD, the topic of skill learning will be briefly reviewed.

### The Time Course of Skill Learning

A recent body of research suggests that the passage of time may play a crucial role in the acquisition of new skills (for a recent review, see Janacsek & Nemeth, 2011). The process of skill acquisition begins with the first exposure to a task. This phase requires a training interval involving repeated engagement with the procedure being learned (Rattoni, Escobar, Pawlik, & Rosenzweig, 2000). This phase is termed *acquisition phase* or *fast learning phase* and is accompanied by fast improvements in performance that can be seen over seconds or minutes (*online learning*). The improvements during initial task practice follow a power function curve, and performance gradually reaches an asymptote. Upon successful completion of acquisition, a slow learning phase is believed to occur, in which slow improvements in performance may be seen within hours to days (*offline learning*). This phase involves a consolidation, whereby new memory traces become increasingly less susceptible to interference (Walker, 2005). The process is typically revealed either by increased resistance to interference, and/or by improvement in performance, following an offline period (Krakauer & Shadmehr, 2006). Several researchers claim that consolidation processes are automatic, occur without intent or awareness (Stickgold & Walker, 2005), and result in skill automaticity (Atienza, Cantero, & Stickgold, 2004; Chee & Chuah, 2008; Fischer, Nitschke, Melchert, Erdmann, & Born, 2005; Kuriyama, Stickgold, & Walker, 2004; Manoach & Stickgold, 2009). Automaticity, in this context, refers to a shift from controlled performance to a more efficient performance (one that is faster, less variable, less vulnerable to interference and with fewer errors) with reduced demands on attention (Schneider & Shiffrin, 1977) and a corresponding shift in brain networks that support performance (Jueptner & Weiller, 1998).

### The Serial Reaction Time Task

One of the experimental paradigms used to study procedural skill learning is the Serial Reaction Time task (SRT; Nissen &

Bullemer, 1987). In this task, participants are presented with a visual stimulus in one of several discrete locations and are requested to make a rapid key press corresponding to the stimulus location. Unknown to the participants, the stimuli appear in a repeated sequence, and learning of the sequence is measured as a decrease in Reaction time (RT) across blocks, or as a difference between RT to sequence and random (or different sequence) blocks (Seger, 1994). Despite the clear evidence of learning, participants are neither able to report the underlying pattern nor recall the sequence (Cohen, Ivry, & Keele, 1990; Curran & Keele, 1993). Thus, this kind of sequential learning has been referred to as *implicit learning* (Berry & Dienes, 1993; Shanks & St John, 1994). The SRT task might tap different learning processes. The decrement in RT following the repeated sequence reflects generalized skill learning (e.g., mapping the specific response to the specific stimulus position) (Ferraro, Balota, & Connor, 1993; Knopman & Nissen, 1987). In addition, the increase in RT when a block with a random or different sequence is presented reflects indirect sequence learning (also termed *transfer*) (Knopman & Nissen, 1987). Recent research has indeed highlighted the importance of studying both processes to gain an understanding of the underlying cognitive mechanisms of special populations, especially when consolidation processes are being investigated (Nemeth & Janacek, 2011; Nemeth et al., 2010).

### Attentional Requirements for Learning?

One of the main questions in the literature is whether skill learning is automatic and can appear independently of attentional resources (for a recent review, see Schwarb & Schumacher, 2012). Several researchers have examined this question by employing a skill learning task within a dual task paradigm (Navon & Gopher, 1980). In this paradigm, participants have to perform primary and secondary tasks simultaneously. If the skill of the primary task is automatized, it will not be disrupted by concurrent processing of the secondary task. If, however, the skill is not automatized, it will be disrupted by concurrent processing of the second task, because both tasks are competing for the same cognitive resources. Most studies demonstrated that the general skill learning component of the SRT task (mapping the specific response to the specific stimulus position) can occur under dual task conditions (Frensch, Lin, & Buchner, 1998; Nissen & Bullemer, 1987; Shanks & Channon, 2002). Furthermore, one study has also demonstrated that this component (S-R compatibility) can actually be enhanced under DA conditions (Roche et al., 2007). In this study, attention was manipulated during acquisition of S-R pair learning. Surprisingly, a concurrent task during the phase of S-R learning led to enhanced learning of the visuomotor association. In relation to the sequence learning component of the SRT task, namely transfer (the increase in RT when a block with a random or different sequence is presented), there appear to be mixed results. Several studies indicated sequence learning does not occur under dual task conditions (Nissen & Bullemer, 1987; Shanks & Channon, 2002), suggesting this kind of learning requires attention. Others, on the contrary, have shown this ability was preserved (Frensch et al., 1998) or at least reduced under dual task conditions compared with single task conditions (Frensch & Miner, 1994; Stadler, 1995). Furthermore, Heuer and Schmidtke (1996) demonstrated that sequence learning under dual task conditions depends on the nature of the secondary

task. Specifically, it was found that visuospatial and verbal memory tasks did not interfere with sequence learning. In contrast, interference was observed while using a go/no-go auditory task. Finally, Cohen et al. (1990) demonstrated that dual task blocked sequence learning of ambiguous structures (each element in the repeated sequence has at least two different followers) but not that of unique (each element has a unique follower) or hybrid (there is at least one unique transition) sequences.

The studies mentioned above concentrated on the first stage of learning. One of the questions remaining open is how attentional allocation might influence later stages believed to be involved in skill learning. A recent study sought to examine how disruption of the declarative component of the SRT task might influence offline learning (Brown & Robertson, 2007). Specifically, it was demonstrated that learning a word list immediately after performing the SRT task resulted in induced offline skill improvements. The authors suggested that the declarative component of the SRT task might be inhibited by the declarative word list task, thus enabling the enhancement of the procedural skill. Although this study did not use a dual task paradigm, it used a declarative task to examine the influence of this interference on later stages of learning. The dual task paradigm might be used as another procedure to inhibit the declarative component of the SRT task. Using this procedure will also help to further clarify the impact of attentional allocation on later stages of learning.

### Skill Learning in DD

A number of studies sought to examine the *Cerebellum Deficit Hypothesis* in individuals with DD using the SRT task. Several studies have revealed impairment in sequence learning among adults with DD as measured by the SRT task (Howard, Howard, Japikse, & Eden, 2006; Menghini, Hagberg, Caltagirone, Petrosini, & Vicari, 2006; Stoodley, Harrison, & Stein, 2006). Other studies have reported intact sequence learning among adults with DD (Kelly, Griffiths, & Frith, 2002; Rüsseler, Gerth, & Münte, 2006). This inconsistency might be attributed to differences in the experimental design, sampling, procedures being used, and so forth. Moreover, Orban, Lungu, and Doyon (2008) claim that the major limitation of these studies is the focus on incidental learning in the fast acquisition phase using the SRT task, while disregarding later stages believed to be involved in the process of skill learning.

### The Current Study

The testing of the *Cerebellum Deficit Hypothesis* in DD using the SRT task has until now been inferred from performance on the SRT task itself. This theory can be strengthened further by examining whether skill learning in DD might be more disrupted by the presence of a secondary task in comparison with normal readers, because of a lack of or reduced level of automaticity. Although several works studied skill learning in DD using a dual task paradigm (Nicolson & Fawcett, 1990; Yap & van der Leij, 1994), neither of them used the SRT task, nor examined later phases believed to be involved in the process of skill learning. In a recent study, both fast and slow phases of skill learning were examined in individuals with DD and normal readers using the SRT task (Gabay, Schiff, & Vakil, 2012a). It was demonstrated that DD was related to a deficit in the acquisition stage of the SRT task,

specifically, in the general skill learning component, while consolidation and sequence learning processes remained intact. Furthermore, DD participants exhibited greater susceptibility to interference compared with normal readers. This pattern was interpreted as a reduced strength of skill automatization. The current study aims to examine empirically whether these reported impairments were attributable to a lack of automatization using a dual task paradigm. Furthermore, it also aimed to assess whether the preserved consolidation processes found in DD were due to the use of conscious compensation strategies. The use of a dual task may prevent the input of greater controlled attentional resources that individuals with DD might use. Therefore, the current study expanded earlier works in three ways: first, it intended to explore how the learning process in the SRT task might be affected by the presence of a secondary task in DD. Second, this question was evaluated not only in the first stage of learning, but in later stages of learning as well. Finally, so far, no study had examined the influence of a secondary task upon consolidation and later stages of learning in the SRT task in normal individuals.

In the present study, DD and control participants completed the SRT task over one practice session (acquisition) and a second session 24 hours later (consolidation). The SRT task was performed by half of the participants under a full attention condition (FA) and by the other half under a divided attention condition (DA). A different sequence taken as indication of sequence learning was introduced only at the second session of learning for three reasons: (a) previous research demonstrated that learning a *different sequence* immediately after a repeated sequence (in first stage of learning using SRT task) impaired offline learning in normal individuals (Goedert & Willingham, 2002). (b) The cerebellar deficit hypothesis suggests a deficit in the cerebellum as the cause that underlies DD (Nicolson et al., 2001). It was demonstrated that patients with cerebellar stroke showed a deficit in motor sequence learning when interrupted by the presentation of a *different block* (Dirnberger, Novak, Nasel, & Zehnter, 2010). (c) It was also demonstrated that DD are impaired in executive functions, which relates to cognitive flexibility and susceptibility to interference (Hedden & Yoon, 2006), that may be caused by the presentation of a *different block*. All of these studies suggest that introducing a different sequence (at first session) might interrupt DDs' learning to a greater extent than normal readers. This assumption was verified in our previous study (Gabay et al., 2012a). DDs' recovery ability from the introduction of a new sequence at the second session was significantly lower than that of controls. As such, introducing a different sequence in the first session would not allow to purely measuring consolidation processes, because it might be confounded with DDs' deficit to recover from the introduction of a new sequence. Orban et al. (2008) stated that in order to assess consolidation and slow learning phases in DD, "one will have to ensure that the subjects with dyslexia overcome their shortcomings during the early learning phase" (p. 168). Mindful of Orban et al.'s views, the current study aimed to maximize DDs' initial acquisition of the motor skill. Therefore, a different block, taken as indication of specific sequence learning, was introduced only at the second session of learning.

The automatization phase of a skill constitutes a stage during which the pattern of responses is consolidated and the processing resources necessary to execute other cognitive tasks become increasingly available with practice (Anderson, 2004). According to

the *Cerebellum Deficit Hypothesis*, individuals with DD may have deficit in acquisition and automatization of new skills (Nicolson et al., 2001). The automatization deficits will be revealed once conscious compensation strategies of individuals with DD are blocked. A secondary task, such as tone counting while performing the SRT task, might block these strategies. It was therefore predicted that the DD group would be impaired in both the acquisition and consolidation stages of skill learning under DA to a greater extent than normal readers, because conscious compensation strategies will not be available.

## Method

### Participants

Participants were 25 young adults with normal reading and 25 adults with DD (*Mean* age = 25.9, *SD* = 2.78, *Mean* age = 24.32, *SD* = 3.1, for the DD and the control groups, respectively). All were undergraduate students of universities and colleges in Israel. Each participant was randomly assigned to one of two groups: divided attention ( $n = 26$ ; 13 controls vs. 13 DD individuals) or full attention ( $n = 24$ ; 12 controls vs. 12 DD individuals). The data of the full attention group are taken from a parallel group of 12 normal readers and 12 developmental dyslexics, previously published in Gabay et al. (2012a). All participants with DD had a well-documented history of developmental dyslexia independently assessed by an educational psychologist. Participants were paid 70 NIS (~\$20) for participating in the experiment, or received course credit for participation. The study was approved by Bar-Ilan University ethics committee, and written informed consent was obtained from participants. All participants were native Hebrew speakers with no reported signs of sensory or neurological deficits/attention deficit hyperactive disorder (according to the [American Psychiatric Association, 1994](#)) and came from families of middle to high socioeconomic status.

All participants underwent a series of cognitive tests to evaluate their general intelligence (as measured Raven Progressive Matrices), verbal working memory (as measured by Digit Span from the Wechsler Adult Intelligence Scale, WAIS-III; Wechsler, 1997), and rapid naming tests (digits/letters). Rapid naming measures were taken from the only individually administered test battery with national norms available in Hebrew, "Alef Ad Taf" (Shany, Lachman, Shalem, Bahat, & Zeiger, 2006). The digit naming speed subtest consisted of five digits each repeated randomly 10 times. The 50 printed digits were presented to the participant, who had to read them aloud as fast as possible. The number of digits per minute was calculated. The letter naming subtest consisted of five (nonfinal) Hebrew letters, each repeated randomly 10 times. The 50 printed letters were presented to the participant, who had to read them aloud, as fast as possible. Number of letters per minute was calculated.

The participants also completed single-word reading tests and a nonword reading tests (Schiff & Kahta, 2009a; Schiff & Kahta, 2009b) to measure reading accuracy and speed abilities. Single-word reading tests were composed of 112 single words (for the accuracy measure subtest) or 104 single words (for the speed measure subtest). Nonword reading tests were composed of 45 nonwords (for the accuracy measure subtest) or 114 nonwords (for the speed measure subtest). In single word and nonword accuracy

subtests the printed words were presented to the participant, who had to read them aloud as accurately as possible. The number of correct words read was calculated. In single-word and nonword speed subtests, the printed words were presented to the participant, who had to read them aloud, as fast and as accurately as possible. The number of correct words read per 45 seconds was calculated.

The two groups did not differ in general intelligence but, as expected, the DD group performed worse than the control group on tests of single-word and nonword reading, as well as on rapid naming tests and verbal working memory. The group with DD comprised 25 students at or below the 50th percentile in both the accuracy and the speed measures (See Table 1).

## Procedure

Stimulus presentation and the recording of response time and accuracy were controlled by a computer program (Super Lab and E-prime). Participants were seated 57 cm from the computer monitor. Participants in the divided attention group were told that they were taking part in an experiment in which they have to perform two tasks concurrently. One of them was introduced as a reaction task to a visual stimulus and the other as a tone-counting task. Participants were first trained on the tone counting task and then on the SRT task. After training ended they were told they have to perform the two tasks concurrently. Participants were told to pay attention to both of the tasks. For participants in the full attention condition the secondary task was not mentioned.

## Stimuli and Design

**SRT task.** In this task, a red light appeared in one of four boxes (5° width by 7° height) arranged horizontally on the computer screen. The distance between the boxes was 5.5°. Participants were given the following instructions: “A red X will appear in one of the four squares on the screen. Using the fingers of your dominant hand, press the key that corresponds to the position of the red X as fast and accurate as possible. In other words, you have to respond with the keys (M, <, >, ?) respectively, for the red X that appears from the left-most to the right-most position.” The red X was 1° width and 1.5° height. The red X position appeared in a

12-trial sequence of repetitions. Nine repetitions of this sequence (i.e., 108 trials) constituted one block. To rule out the possibility that a specific sequence will lead to learning, half of the participants in each group were trained in one sequence (342312143241) and the other half in another sequence (341243142132). The sequences were balanced for location frequency (each location occurred three times), transition frequency (each possible transition from one location to a different one occurred once), reversal (e.g., 1–2–1) frequency (one in each sequence), repetitions (no repetitions in either sequence), and rate of full coverage (Reed & Johnson, 1994). The only difference between the sequences was in their second-order conditional structure. For example, 3–4 was followed only by a 2 in the first sequence but only by a 1 in the second sequence. The next target spatial location appeared on the screen within 5 seconds or as soon as a response was made, whether the response was correct or incorrect. Reaction time (RT) was defined as the time from onset of the stimulus to pressing of the response key. Reaction time was recorded automatically by the computer for correct responses; only incorrect responses were recorded as errors. The response-stimulus interval (RSI) was 0 ms to hamper the development of explicit awareness (Destrebecqz & Cleeremans, 2001). In the first session, participants were presented with three blocks, with a 45 second rest between blocks. The starting point of the repeating sequence was different in each block to minimize the likelihood of participants’ gaining declarative knowledge while performing the task (Willingham, Salidis, & Gabrieli, 2002). In the second session (24 hours after the first), participants were presented with three blocks. The first had the same sequence as in the first session, the second block had a new sequence and the last block had the same sequence as in the three blocks of the first session.

**Tone counting task.** In each block of dual-task RT trials, a 100-ms computer generated tone was emitted immediately after each correct target location response. Each tone was randomly determined to be either low (1,000 Hz) or high (2,000 Hz), and participants were instructed to count the number of high tones emitted during each block of trials. At the end of each block, the experimenter entered the room and participants were asked to provide him with their count. The experimenter typed this count into the computer. If participants made more than 10% errors, they were told their error percentage and were encouraged to try harder to attend to their tone-counting accuracy. Participants who made more than 10% errors in the tone counting task were not included in the analysis. All the participants performed the tone counting task with the same level of db.

Table 1  
*Cognitive and Literacy Scores for the Control and DD Group Samples*

Subtest	Group		<i>p</i>
	Control	DD	
Raven	56.32	54.88	n.s.
Digit span	12.4	9.2	**
Letter naming	18.56	22.72	**
Digit naming	16.52	20.84	**
Word reading speed	81.8	61.56	**
Word reading accuracy	106.08	93.56	**
Non-word reading speed	54.96	26.32	**
Non word reading accuracy	37.44	20.92	**

*Note.* The values of word and non-word reading speed subtests represent the number of correct responses participants made in 45 seconds. The values of word and non-word reading accuracy subtests represent the number of correct responses participants made.

\*\*  $p < .01$ .

## Explicit Knowledge

Upon completion of the task, participants were debriefed promptly and were asked the following questions: “Did you notice anything different about the tasks?” “Was there a pattern or sequence present in the task?” “If you noticed any sequence, could you try generating it?” After that, participants were informed that they were presented with a repeated sequence in the first three blocks (first session) and in the first and third blocks (second session). They were presented with a series of stimuli and were asked to push the response button in the location where they predict the next stimulus would appear according to the sequence presented during the task. After the response, whether right or

wrong, the target moved to the next right position. The participants were told that in this task they would not be timed and should focus on being correct, rather than being fast. The number of correct positions selected out of the position sequence was recorded. This task was designed to test the explicit memory of the SRT task sequence. It should be noted that the ability of the generate task to measure explicit knowledge has been criticized (Perruchet & Amorim, 1992), but it is nevertheless an acceptable measurement for explicit knowledge.

## Results

### Primary Task - SRT Task RT and Mean Accuracy Rate

A median measure was used, because it is less influenced by extreme responses (in comparison to mean) and is the most acceptable procedure when measuring RTs in sequential learning tasks (Howard et al., 2004; Willingham & Goedert-Eschmann, 1999). The mean of the median (of 12-item sequence) RT per block (i.e., 108 trials) was analyzed. The number of errors (i.e., incorrect responses) was analyzed as well. Figures 1 and 2 present the median RT/mean accuracy as a function of blocks of the SRT task for both groups in the DA and FA conditions.

The groups (DD and control) were compared on different learning measures of the SRT task: first is the *learning rate (acquisition)* across the three blocks of the repeated sequence in the first session; second is the effect of overnight delay by comparing the first block of the second session to the last block of the first session, which would indicate *consolidation*; third is the *transfer* by comparing the repeated sequence (i.e., first block, second session) and the different sequence (i.e., second block, second session). The *recovery from interference* was also assessed by comparing a different sequence (i.e., second block, second session) to the repeated sequence (i.e., third block, second session). In addition, the groups were compared on the generate task, which reflects *explicit knowledge* of the repeated sequence.

### Learning Rate—Blocks 1–3, First Session

The mean of the median RT and the mean accuracy rate of the two groups in all three blocks of the first session was submitted to a mixed-design ANOVA with group (DD vs. controls) and con-

dition (full/divided attention) as between-subjects factors and learning trials as a within-subjects factor. Overall, the DD group was slower than the control group,  $F(1, 46) = 6.701$ ,  $MSE = 227422$ ,  $p < .05$ . There was also a main effect for condition. Overall, participants were slower in the divided attention condition compared with the full attention condition,  $F(1, 46) = 83.71$ ,  $MSE = 2723817$ ,  $p < .05$ . There was also a main effect for learning,  $F(2, 92) = 36.416$ ,  $MSE = 98119$ ,  $p < .05$ . In addition, the condition by learning interaction reached significance,  $F(1, 22) = 4.633$ ,  $MSE = 12485$ ,  $p < .05$ . Importantly, there was a reliable interaction of learning, condition, and group,  $F(2, 90) = 4.907$ ,  $MSE = 13220$ ,  $p < .05$ . To analyze this interaction, separate 3 (block)  $\times$  2 (group) ANOVAs were computed for each condition. For the full attention condition, the group by learning interaction was significant,  $F(2, 44) = 3.55$ ,  $p < .05$ . Further analysis revealed that in the FA condition the controls and DD group showed a similar decrease in the RT to the second block compared with the first block,  $F(1, 22) = 1.178$ ,  $MSE = 544$ ,  $p < .1$  ( $M = 49$  ms,  $SD = 34$  ms for the controls;  $M = 64$  ms,  $SD = 31$  ms for DD). Nevertheless, whereas the control group showed significant reduction in the RT to the third block compared with the second block  $F(1, 11) = 10.214$ ,  $MSE = 305$ ,  $p < .05$  ( $M = 22$  ms,  $SD = 24$  ms), the DD group showed a significant *increase* in RT to the third block compared with the second block,  $F(1, 11) = 4.831$ ,  $MSE = 237$ ,  $p = .05$ , ( $M = 13$  ms,  $SD = 21$  ms). For the DA condition, the group by learning interaction was significant,  $F(2, 48) = 3.719$ ,  $MSE = 17248$ ,  $p < .05$ . Further analysis revealed that only the control group showed a significant decrease in RT in the second block compared with the first block,  $F(1, 24) = 22.38$ ,  $p < .05$ . The DD group did not show the expected decrease,  $F < 1$ . In the third block, the DD group showed significant decrease in RT compared with the second block,  $F(1, 24) = 11.53$ ,  $p < .05$ , whereas the control group did not,  $F < 1$ . A nonlinear analysis was conducted in order to examine the qualitative difference between the learning curves of the DD group under FA and DA conditions. The results indicated a quadratic significant trend,  $F(1, 23) = 9.311$ ,  $p < .05$  (the linear trend was not significant,  $p > .1$ ), suggesting a qualitative difference between the two curves. In the mean accuracy rate, only the condition effect was significant, indicating participants were more accurate in the DA as compared with the FA condition,  $F(1, 46) = 28.542$ ,  $MSE = 0.210$ ,  $p < .05$  (91.1%, 98.6%, in the FA and DA conditions, respectively).

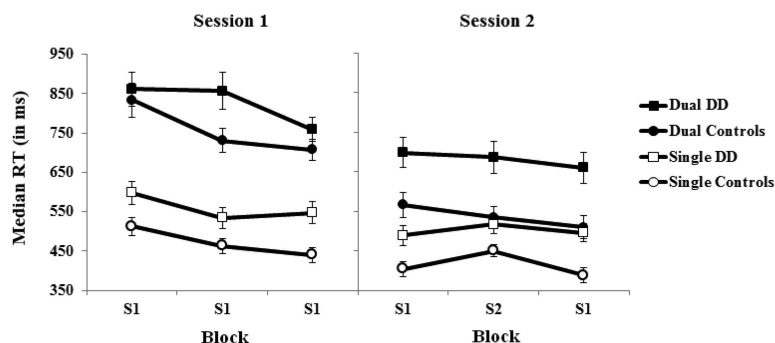


Figure 1. Mean of the median RT of the DD and control groups in the first and second session in the SRT task under FA and DA conditions. Error bars represent standard errors.

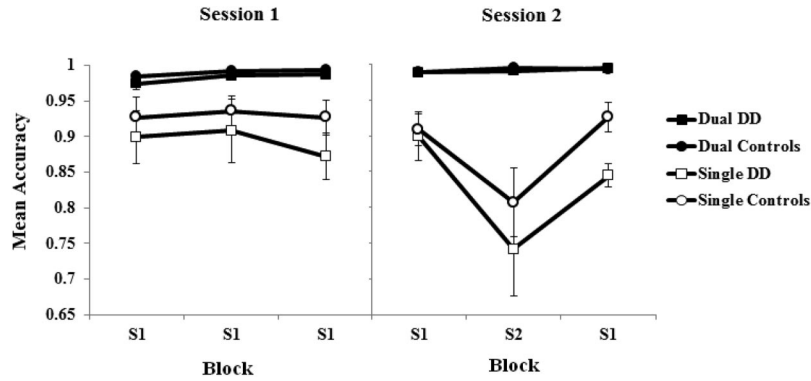


Figure 2. Mean accuracy of the DD and control groups in the first and second session in the SRT task under FA and DA conditions. Error bars represent standard errors.

### Consolidation—Block 3, First Session Versus Block 1 Second Session

There was a main effect of group indicating that the DD group was overall slower than the control group,  $F(1, 46) = 12.15$ ,  $MSE = 219861$ ,  $p < .05$  ( $M = 623.29$  ms,  $SD = 19.04$  ms for the DD;  $M = 529.44$  ms,  $SD = 19.04$  ms for the controls). The main effect for condition indicated that participants were faster in the FA condition compared with the DA condition,  $F(1, 46) = 62.243$ ,  $MSE = 1126725$ ,  $p < .05$ . There was a main effect for consolidation as manifested in an overall decrease in the RT to the first block (second session) compared with the last block (first session),  $F(1, 46) = 59.041$ ,  $MSE = 136885$ ,  $p < .05$ . Importantly, there was a reliable interaction of consolidation, condition, and group,  $F(1, 46) = 7.35$ ,  $MSE = 17048$ ,  $p < .05$ . To analyze this interaction, separate 2 (block)  $\times$  2 (group) ANOVAs were computed for each condition. For the full attention condition, the consolidation by group interaction did not reach significance,  $F(1, 22) = 2.180$ ,  $MSE = 669$ ,  $p > .05$ . In the divided attention condition, the consolidation by group interaction was significant,  $F(1, 24) = 5.778$ ,  $MSE = 22111$ ,  $p < .05$ . Further analysis revealed that both groups showed decrease in RT to the first block (second session), compared with the last block (first session),  $F(1, 24) = 34.17$ ,  $p < .05$ , for the control group and  $F(1, 24) = 5.99$ ,  $p < .05$ , for the DD group, yet this decrease was greater for the control group. In the mean accuracy rate, only the condition effect was significant, indicating that participants were more accurate in the DA as compared with the FA condition,  $F(1, 46) = 34.61$ ,  $MSE = 0.193$ ,  $p < .05$  (90.1%, 98.6%, in the FA and DA conditions, respectively).

### Transfer—Block 1 (Second Session) Versus Block 2 (Second Session)

The DD group was slower overall, as indicated by the main effect for group,  $F(1, 46) = 14.91$ ,  $MSE = 296118$ ,  $p < .05$ . There was a main effect for condition, indicating that participants were faster in the FA as compared with the DA condition,  $F(1, 46) = 30.858$ ,  $MSE = 613021$ ,  $p < .05$ . The transfer effect was not significant,  $F(1, 46) = 1.064$ ,  $MSE = 1528$ ,  $p = .307$ . The interaction of transfer by condition was significant,  $F(1, 46) = 14.768$ ,  $MSE = 21203$ ,  $p < .05$ . Further analysis revealed that, in

the FA condition, there was significant increase in RT to the second block (second session) compared with the first block (second session),  $F(1, 46) = 11.422$ ,  $p < .05$ . In the DA condition, there was a decrease in RT between those two blocks,  $F(1, 46) = 4.11$ ,  $p < .05$ , suggesting no learning of the repeated sequence under DA conditions. The triple interaction did not reach significance,  $F(1, 46) = 1.26$ ,  $p = .210$ . In relation to mean accuracy rate, participants were more accurate overall on the DA condition compared with the FA condition,  $F(1, 46) = 29.96$ ,  $p < .05$  (83.8%, 99%, in the FA and DA conditions, respectively). There was also a main effect for transfer, indicating participants were less accurate in the second block (second session, 88.3%) compared with the first block (second session, 94.6%). The interaction of transfer by condition was also significant,  $F(1, 46) = 12.354$ ,  $p < .05$ . Further analysis revealed that, in the FA condition, participants made significantly more errors in the different block (block 2, second session, 77%) compared with the repeated block (block 1, second session, 90.3%),  $F(1, 46) = 24.322$ ,  $p < .05$ . By contrast, in the DA condition, there was no difference between those two blocks,  $F < 1$  (98.8%, 99.3%, in the repeated and different blocks, respectively).

### Recovery From Interference—Block 2 (Second Session) Versus Block 3 (Second Session)

The DD group was slower overall than the control group,  $F(1, 45) = 19.56$ ,  $MSE = 367090$ ,  $p < .05$  ( $M = 589.63$ ,  $SD = 19.37$ ,  $M = 470$ ,  $SD = 19.37$ , for the DD and control groups, respectively). There was also a main effect for condition, indicating that participants were faster in the FA compared with the DA condition,  $F(1, 46) = 24.496$ ,  $MSE = 458805$ ,  $p < .05$ . The recovery effect reached significance,  $F(1, 46) = 13.086$ ,  $MSE = 28609$ ,  $p < .05$ . The triple interaction was not significant,  $F(1, 46) = 1.29$ ,  $p > .05$ . In relation to accuracy mean rate, there was a trend suggesting the control group was more accurate than the DD group,  $F(1, 46) = 3.474$ ,  $p = .06$  (93%, 89.2%, in the control and DD groups, respectively). There was a main effect for condition, indicating participants were more accurate in the DA as compared with the FA condition,  $F(1, 46) = 65.674$ ,  $MSE = 0.668$ ,  $p < .05$  (82.9%, 99.3%, in the FA and DA conditions, respectively). There was a main effect for the recovery measure, indicating that participants were more accurate in the repeated block (block 3, second

session) compared with the different block (block 2, second session),  $F(1, 46) = 7.441$ ,  $MSE = 0.076$ ,  $p < .05$ , 93.9%, 88.3% in the repeated and different blocks respectively). The recovery by condition interaction was also significant,  $F(1, 46) = 7.236$ ,  $MSE = 0.076$ ,  $p < .05$ . Further analysis revealed that, in the FA condition, participants were more accurate in the repeated block (block 3, second session, 88.5%) compared with the different block (block 2, second session, 77.4%),  $F(1, 46) = 14.11$ ,  $p < .05$ . In contrast, in the DA condition there was no difference between those two blocks,  $F < 1$  (99.3%, 99.3%, in the repeated and different blocks respectively). This similarity in the pattern of accuracy data raises the possibility of a ceiling effect. In the future it would be worthwhile to increase task difficulty to highlight differences in performance between DD and control group participants.

### Individual Differences

Figure 3 presents a scatterplot of the individual acquisition and consolidation difference scores under DA for the two groups: the higher the score, the stronger the learning. The DD group was mainly impaired during the first learning phase in the transition from the first block to the second block in the first session. Accordingly, we calculated an acquisition score for each individual that compared the performance between the first and second blocks (subtracting mean median RT in block 2 from mean median RT in block 1, first session). The consolidation score, on the other hand, was calculated by subtracting the mean median RT in block 1, second session from the mean median RT in block 3, first session. As can be seen in this figure, the majority of the control group exhibited learning in both measures, whereas the majority of

the DD group did not exhibit learning at all or showed reduced learning in both measures in comparison with the control group.

### Explicit Knowledge

The mean number of correct sequence positions generated by the two groups in both conditions was submitted to a mixed-design ANOVA with group (DD vs. controls) and condition (full/divided attention) as between-subjects factors and generate as a within-subjects factor. There was a trend indicating that participants generated less correct sequence positions under DA as compared with FA conditions,  $F(1, 46) = 3.877$ ,  $p = .054$  (31.1%, 40.9% of correct response respectively). The interaction of group by condition was not significant,  $F(1, 46) = 1.42$ ,  $p = .237$ , indicating that neither group differed significantly in the number of correct sequence positions generated, in both the FA conditions (45%, 36%, of correct response for the control and DD groups, respectively) and the DA condition (30%, 32%, of correct response for the control and DD groups, respectively).

### Secondary Task - Tone Counting Task

Means of error rates across blocks of the two groups in both sessions were submitted to a mixed-design ANOVA with group (DD vs. controls) as a between-subjects factor and session (first, second) as a within-subjects factor. The analysis revealed that the DD group made more errors overall than the control group in the tone counting task,  $F(1, 24) = 8.786$ ,  $p < .05$ ,  $M = 4.789$ ,  $SD = 0.54$ ,  $M = 2.49$ ,  $SD = 0.54$ , for the DD and control groups respectively. There was also a main effect for session,  $F(1, 24) = 4.429$ ,  $p < .05$ , indicating that participants made more errors in the first session as compared with the second session ( $M = 4.23$ ,  $SD = 0.48$ ,  $M = 3.04$ ,  $SD = 0.47$ , respectively). The interaction of group by session was not significant,  $F < 1$ .

### Discussion

The present study explored the effect of dual task settings on acquisition and consolidation of a skill in both DD and control participants. The impact of dual task costs on participants' performance was taken as an indication of automaticity. The primary task used was the SRT task and the secondary task was a tone counting task. The crucial test was the difference between the learning measures under DA and FA conditions in both normal readers and individuals with DD. The results will be introduced in relation to the different learning measures elicited from the procedure being used (acquisition, consolidation, sequence learning).

Consistent with previous reports in the literature (Nissen & Bullemer, 1987; Shanks & Channon, 2002), the DA task of tone counting interfered with the sequence learning component in both DD and control groups. Although both groups showed a transfer under FA conditions, there was no indication of transfer in either of the groups under DA conditions. The sequence used was ambiguous and had previously been found to interfere with sequence learning (Cohen et al., 1990). The tone counting task has also been documented previously as a secondary task which hampers the development of sequence knowledge (Shanks & Channon, 2002).

The main difference between the two groups was evident in the acquisition and consolidation measures. In relation to acquisition,

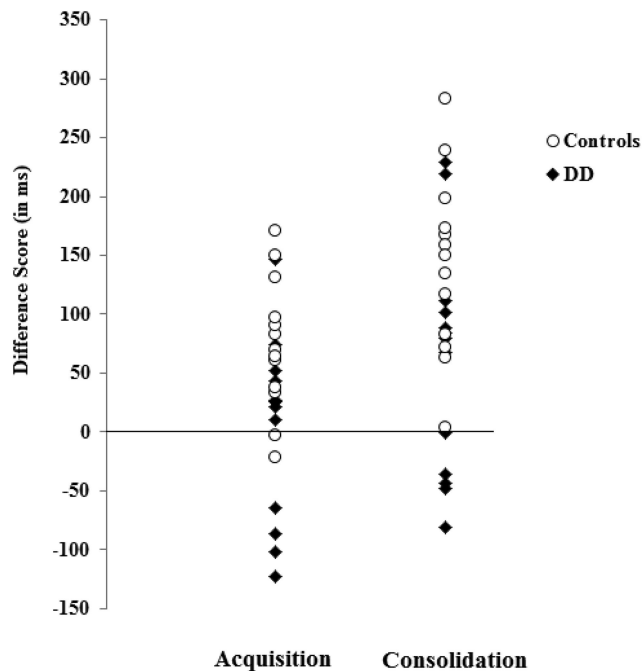


Figure 3. A scatterplot of the individual acquisition and consolidation difference scores for the DD and control groups.



it seems that DA enhanced the performance of the general learning skill component of the two groups. An indication for enhanced learning under DA compared with FA conditions was evident in both RT and accuracy measures. These results are in accordance with previous research, which demonstrated that a dual task might enhance associative visuomotor learning (Roche et al., 2007). Another possibility is that under DA conditions participants initially take more time in performing the two tasks. That leaves them with the opportunity to improve substantially in later stages of the task. Nevertheless, it appears that DA had a differential influence on the learning process of the DD and control groups. Although control participants were slower in the DA compared with the FA condition, in both conditions they exhibited the typical learning curve usually demonstrated in the SRT task. In contrast, there was a significant difference in the learning process of the DD group at the first session under DA and FA conditions. Although DD exhibited atypical learning curves in both conditions, the shape of the curve was qualitatively different under DA compared with FA conditions. In the FA, DD participants showed a significant decrease in RT from the first repeated block to the second one, whereas there was an increase in RT to the last repeated block. In contrast, in the DA condition, participants with DD did not show the expected decrease in RT in the second repeated block compared with the first block, whereas a significant decrease was observed in the final repeated block. Both controls and individuals with DD received the same amount of training, but only the control group showed the expected decrease in RT in the second block. It is suggested that individuals with DD have a deficit in the general skill learning component of the SRT task. Sequence learning and general skill learning could not be dissociated at the first session of learning. Nevertheless, the fact that the two groups did not show sequence learning under DA in the second session suggests the absence of this component as well in the first stage of learning.

This type of pattern suggests that a secondary task seems to delay the acquisition of a new skill in the DD group in comparison with normal readers. It is also suggested that DD individuals may use conscious compensation strategies while performing the SRT task under FA (at least initially). But once these strategies are no longer available as a result of the interference of a dual task, they may not reach the same level of performance as normal readers. By definition, automaticity in a given task has been achieved once performance is minimally affected by other ongoing tasks (Logan, 1979). If skill learning is more affected by the presence of an ongoing task in DD as compared with normal readers, this would imply individuals with DD may suffer from a deficit in skill automatization. This finding is in accordance with previous research indicating that individuals with DD experienced more interference from the presence of ongoing tasks compared with normal readers in the first stage of skill learning (Nicolson & Fawcett, 1990; Yap & van der Leij, 1994).

An unpredicted result regarding normal participants relates to the consolidation measure. The present study demonstrates for the first time that consolidation of a motor skill (specifically the general learning skill component of the SRT task) can be enhanced under DA. The decrease in RT following sleep was greater under DA as compared with FA conditions in control participants. This kind of result may be attributable to the declarative and procedural components involved in the SRT task. For example, previous research demonstrated that performing a declarative task immedi-

ately after the SRT task enhanced offline learning in normal participants (Brown & Robertson, 2007). The authors suggested that the declarative task inhibited the declarative component of the SRT, thus enabling enhancement of the procedural component which resulted in greater consolidation of the motor skill. The same explanation may be responsible for the results of the current study. It is possible that the secondary task performed during the SRT task inhibited development of the declarative component, thus enabling the enhancement of procedural components. Thus, DA may modulate memory consolidation, which may imply that not all kinds of human learning depend on attentional resources. This notion is also in accordance with previous research demonstrating that irrelevant perceptual learning can occur without attention in both the visual (Watanabe, Náñez, & Sasaki, 2001) and the auditory modalities (Seitz et al., 2010). It is particularly in accordance with previous works indicating that attention to performance might be counterproductive, as practice builds an increasingly automated performance repertoire (Baumeister, 1984; Beilock & Carr, 2001; Beilock, Carr, MacMahon, & Starkes, 2002).

The enhanced consolidation was not apparent in the DD group. DA did not modulate consolidation in DD participants as compared with normal readers. In fact, the amount of consolidation in this group was the same in the DA condition as compared with the FA condition. It may be logical to assume that DA interferes with skill enhancement in individuals with DD in contrast to normal readers. This line of results may be accounted for in terms of a deficit in skill automaticity in DD. If consolidation results in skill automaticity, as suggested by several investigators (Atienza et al., 2004; Chee & Chuah, 2008; Fischer et al., 2005; Kuriyama et al., 2004; Manoach & Stickgold, 2009), a lack of enhancement of the procedural skill under DA may reflect a deficit in the automatization of the procedural skill in DD. In a previous study, we suggested that consolidation processes in DD may be preserved (Gabay et al., 2012a). Yet this preserved ability may be attributable to conscious compensation strategies used by individuals with DD. If so, the core automaticity deficits of DD remained unrevealed. However, under DA conditions, individuals with DD may not have the cognitive resources to compensate for their performance, because they are occupied by the presence of a secondary task. The present study demonstrates an atypical expression of consolidation processes in DD under DA conditions and is therefore in accordance with both the *Cerebellum Deficit Hypothesis* (Nicolson et al., 2001) and the *Conscious Compensation Hypothesis* (Nicolson & Fawcett, 1994b). Additionally, the present study broadens these views further by demonstrating a deficit in procedural skill automatization in DD not only in the first stage of the learning process, but also in later stages believed to be involved in skill learning. The present results are also in accordance with previous research in the field of consolidation and learning disabilities, which revealed delayed and atypical acquisition and atypical consolidation in individuals with language impairments (Adi-Japha, Strulovich-Schwartz, & Julius, 2011) and ADHD (Adi-Japha, Fox, & Karni, 2011).

It should be noted that automatization deficit is not the only interpretation that can account for the current results. One may argue that DD attentional problems may lead to greater impairments in tasks which require more attention (DA), in comparison with tasks which require less attention (FA). Indeed, the attentional

deficits of individuals with DD are well documented in the literature (for a review see Valdois, Bosse, & Tainturier, 2004). In addition, previous research revealed impaired dual task performance in participants with ADHD, but not in participants with pure DD (Raberger & Wimmer, 2003). Although the present study examined adults with DD without ADHD contamination (according to the DSM criteria), one cannot exclude completely the possibility of attention problems in our DD sample. Thus DDs' poor dual task performance may be interpreted in terms of impaired automaticity but also as impaired attentional resources. As mentioned earlier in the introduction, there are several views of impaired attention in DD, and the question of which component of attention is impaired in DD is controversial. The attention component which may be the most relevant to dual task settings is the control executive attention, which is defined as the ability to maintain memory representation in the face of interference (Engle, Tuholski, Laughlin, & Conway, 1999). Thus, the interpretation of the current results in terms of impaired attention would be primarily in accordance with attention view of DD, which points to a deficit in the executive component of attention.

The current study was not designed to differentiate between the impaired automaticity versus attention views of DD (for similar discussion see Moores, Nicolson, & Fawcett, 2003). It is also questionable whether these two processes can be actually differentiated. In the field of skilled performance, automaticity is thought to work with attention as "the hands and feet of genius" (William & Harter, 1899, p. 375). Additionally, it was suggested that studies demonstrating dependence between attention and automaticity represent a truer picture of the phenomenon of automaticity than studies that assert independence (Logan, 1985). Thus, attention and automaticity might represent two sides of the same problem, because the definition of automaticity is based on attention (automaticity is defined as processing without attention; Posner & Snyder, 1975). Even if attention and automaticity could be empirically separated, we believe that the interpretation of impaired automaticity is worth consideration, because of the unique pattern of the results obtained. The current study demonstrated general skill learning enhancement under DA in normal readers for both first (acquisition) and later stages of learning (consolidation). This pattern implies that focusing of attention (FA condition) had a negative influence on learning and that employing attention by a secondary task (DA condition) was beneficial for general skill learning. Thus, one might find it difficult to explain DDs' deficits in terms of impaired attentional resources for the sort of learning which can actually benefit from distraction (such as performing additional tone counting task). It would be more compelling to assume DDs' impaired performance under DA stems from poor automaticity. Nevertheless, the attentional deficits in individuals with DD cannot be underestimated, they are well documented and play a central role in DD etiology (Facoetti et al., 2010; Franceschini et al., 2012; Valdois et al., 2004). Yet, we believe that automatization deficit may provide a possible partial explanation of the underlying cause of DD and can contribute further to the attentional problems which have been observed in this population.

The understanding that simple basic skills are poorly automatized in DD is important for DD management. Individuals with DD may suffer from a deficit in automatization processes that are built-in in any language (reading, spelling) or motor skills (writing, balancing) they may attempt to acquire. All those skills were found

to be deficient in individuals with DD (Nicolson & Fawcett, 1994a; Stoodley, Fawcett, Nicolson, & Stein, 2005; Vellutino et al., 2004).

The current results also contribute additional predictions regarding the neural substrates that underlie DD. Previous behavioral, lesion, and neuroimaging studies demonstrated cerebellar plasticity during skill learning due to the stage of learning, as well as the nature of the task (for a review see Doyon & Benali, 2005). It seems that both the cerebellum and striatum play a critical role in the first stages of sequence learning, while the striatum is essential for later stages of learning. The present study demonstrated atypical performance in both early and later stages of skill learning in individuals with DD. Based on this, one could assume a deficit in both the cerebellum and striatum in individuals with DD because of their critical involvement in skill learning and skill automaticity. Similarly, Nicolson and Fawcett (2011) recently suggested a neuronal framework involving both the cerebellum and the striatum in the underpinnings of different developmental disorders as well as DD (for recent behavioral evidence supporting this framework, see Gabay, Schiff, & Vakil, 2012b). Indeed, there is an accumulating body of evidence suggesting functional and anatomical differences in the cerebellum of individuals with DD (Brambati et al., 2004; W. Brown et al., 2001; Eckert et al., 2003; Finch, Nicolson, & Fawcett, 2002; Laycock et al., 2008; Nicolson et al., 1999; Pernet, Poline, Demonet, & Rousset, 2009; Rae et al., 1998; Vlachos, Papathanasiou, & Andreou, 2007). Thus, the current study further supports these findings by adding new behavioral evidence that links DD to a cerebellar dysfunction. It should be noted that cerebellar signs in DD might not necessarily reflect cerebellar dysfunction. Rather, it is also possible that cerebellar signs might be a result of faulty input via impaired magnocellular pathways (Zeffiro & Eden, 2001). More research is needed to investigate these issues further. As for the striatum, which may be also deficient in DD as implied by the current results, further anatomic research is necessary to clarify its specific role in DD etiology.

In conclusion, the present study aimed to examine the influence of dual task settings on both acquisition and consolidation processes in normal readers and DD. This influence was taken as an indication of skill automaticity. Taken together, the results suggest that a dual task might enhance memory consolidation in normal readers. Importantly, it is demonstrated that DD automatization deficits may be evident not only in the acquisition stage of a skill, but also in the consolidation processes which seem to be essential for the development of skill mastery.

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14. Issue Date for Circulation Data Below: **September 2012**

15. Extent and Nature of Circulation

		Average No. Copies Each Issue During Preceding 12 Months	No. Copies of Single Issue Published Nearest to Filing Date
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17. Signature and Title of Editor, Publisher, Business Manager, or Owner  
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 Director, Service Center Operations

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