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COGNITIVE FUNCTION IN AUTISM

Summary of Ph.D. Thesis

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The topic and the structure of the dissertation

The study of focused cognitive functions (working memory, learning) enables mapping the neurocognitive background of school achievement, which may help in the diagnostics of neurocognitive problems, atypical development and helps with the development of more effective improvement methods. Working memory capacity and executive functions have an essential role in learning (*Kane and Engle*, 2002; *Alloway, Gathercole*, *Adams*, *Willis, Eaglen and Lamont*, 2005). Autism spectrum disorders (ASD) are characterized by inflexible, repetitive behavior, there is evidence that executive function deficits contributes to the core symptoms (*Baron-Cohen, Bolton*, 2000; *Ozonoff*, 1997). Autistic people have shown impairments in various learning and memory tasks (*Németh, et al*., 2010). Numerous research studies on working memory, executive functions, implicit and explicit learning have been published, but there are few studies that deal with all of them in ASD. The study is important because it helps to understand the operation of cognitive functions in autism and helps to develop more effective improvement methods.

I submit three Experiments in my Ph.D. thesis.

Experiment I.:

Our first study examined working memory in an autistic sample. The theory of executive dysfunction (*Ozonoff*, 1997) draws attention to the role of frontal lobes in daily activities. Task-relevant information must be maintained in working memory as it is supposed to play a critical role in human cognition. Earlier examinations have found mixed evidence of working memory impairment in autism. Our goal was to get our results compared with learning abilities.

We expected impaired performance in working memory tasks compared to the both an age-matched control and an IQ-matched control group. The present study found intact verbal memory (Digit span test) but impairment across two tasks (Listening span test and Counting span test), that suggest complex working memory in ASD is not intact.

Experiment II.:

Our second study investigated implicit learning mechanisms in autism. The autistic symptoms in daily activities, tasks, and routine show impairments, we need to investigate the unknown background processes (*Howling*, 2005). Implicit skill learning, with its unconscious and statistical properties, underlies not only motor but also cognitive and social skills.

We expected that implicit learning is intact in the group of children living with autism compared to the control groups (age-matched and IQ-matched control). Our question was whether consolidation is impaired in autism and control. We investigated probabilistic implicit sequence learning and its consolidation in ASD. Three groups of children participated: thirteen with high-functioning ASD, 14 age-matched controls, and 13 IQ-matched controls. All were tested on the Alternating Serial Reaction Time Task (ASRT, *Howard and Howard*, 1997), making it possible to separate general skill learning from sequence-specific learning. The ASRT task was repeated after 16 hours. We found that control and ASD children showed similar sequence-specific and general skill learning in the learning phase. Consolidation of skill learning and sequence-specific learning were also intact in the ASD compared to the control groups. These results suggest that autistic children can use the effects/results of implicit learning not only for a short period but also for a longer stretch of time.

Experiment III.:

Our third study examined explicit learning requires the conscious observation (*Baddeley*, 2001). Higher-level cognitive functions and memory performance shows deficits in autism that render more difficult explicit learning (*Johnson et al.*, 2007; *Williams, Goldstein and Minshew*, 2002). We investigated whether explicit learning and consolidation are impaired in autism.

We expected that explicit learning is impaired in autism compared to the aged and mentally aged control group. Our question was about consolidation and off-line learning mechanisms both in autistic and control group. The groups were tested on the modified Alternating Serial Reaction Time Task (ASRT, *Song et al.*, 2007) in two Sessions: a learning phase (Session 1) and a testing phase (Session 2) separated by a 16-hour interval. In the first

Session we investigated probabilistic implicit sequence learning in both groups, but in the second Session we found significance on reaction time, ASD group seemed to be slower. The reason why it could happen was possible that autistic children became disturbed by the explicit and implicit elements. We found consolidation in both groups, but autistic children were slower and had fewer balanced learning mechanisms.

These results may help in the detection of working memory, learning impairments in children with learning difficulties, in the diagnostics of atypical development and to develop more effective improvement methods. Our results may be important not only to pedagogy and school psychology but also to the neuropsychological practice. An interdisciplinary approach may serve as a useful tool for the more accurate and more detailed understanding of the background and individual differences in school achievement.

Theoretical background and conceptions

Working memory capacity have an essential role in learning, and may fundamentally determine achievement in school (*Kane and Engle*, 2002; *Alloway, Gathercole, Adams, Willis, Eaglen and Lamont,* 2005; *Gathercole, Alloway, Willis* and *Adams*, 2006; *Gathercole, Pickering, Knight and Stegman*, 2004). The theory of executive dysfunction (*Ozonoff*, 1997) draw attention to the role of frontal lobes in the daily activities. Task-relevant information must be maintained in working memory supposed to play a critical role in human cognition. Earlier examinations have found mixed evidence of working memory impairment in autism. Our goal was to get our results compared with learning abilities.

Learning procedures are complex, require implicit and explicit processes. Implicit learning is defined as the acquisition of information or motor skill without conscious access to what was learned or even to the fact that learning occurred (*Shanks, St. John,* 1994). Autism Spectrum Disorder is characterized by social, communicative and motor impairments (*APA*, 2013). The semantic and episodic memories of people with autism have often been studied, but neurocognitive studies of procedural learning and implicit cognition have received less attention. The extent of learning abilities of ASD individuals is debated (*Dawson et al*., 2008). We examined implicit learning in ASD to probe the functional integrity of this type of fundamental learning mechanism. Explicit learning goes on conscious way (*Baddeley*, 2001), explicit processes suffer more under circumstances with IQ impairment. If learning relies on explicit strategies, then autistic individuals could learn less than controls due to impairments in explicit rather than implicit learning (*Németh, et al*., 2010).

Autism Spectrum Disorders are characterized by significant impairments in social reciprocity, communication, accompanied by patterns of repetitive behaviors and interests (*APA*, 2013). Autism spectrum disorders (ASD) are characterized by inflexible, repetitive behavior, there is evidence that executive function deficits contribute to the core symptoms (*Baron-Cohen, Bolton*, 2000; *Ozonoff*, 1997).

This paper, in addition, reviews working memory, implicit and explicit learning processes, in ASD. We discuss the main objectives, hypothesis, subjects and results of the study in Table 1.

Table 1. The outline of the four experiments

	Objectives	**Hypotheses**	**Participants**	**Methods**	**Results**
First study	Investigation of working memory capacity in ASD (in the framework of Ozonoff, 1997).	We expect impairments in working memory in ASD compared to the control groups.	N=124 (ASD: N=31, Aged control: N=59, IQ control: N=34)	Digit span test Listening span test Counting span test	- Intact verbal memory (on Digit span test) in ASD. - Impaired complex working memory (on Listening span test and Counting span test) in ASD.

	Objectives	Hypotheses	Participants	Methods	Results
Second study	1. Investigation of implicit learning processes in ASD and typically developing children. 2. Investigation of consolidation (off-line learning) in ASD and typically developing children.	1.We expect intact implicit learning in ASD. 2.Investigation to whether consolidation is intact.	N=40, (ASD: N=13, Aged control: N=14, IQ control: N=13)	Implicit ASRT	- Intact implicit learning in ASD. - We did not find neither off-line sequence learning nor off-line motor learning in any group. - Intact consolidation in ASD and in control groups.
Third study	1. Investigation of explicit learning processes in ASD and typically developing children. 2. Investigation of consolidation (off-line learning) in ASD and typically developing children.	1. We expect impairments in explicit learning processes in ASD. 2. Investigation to whether consolidation is intact.	N=32 (ASD: N=16, IQ and aged control: N=16)	Explicit ASRT	- No significance in sequence learning and motor skill learning. - ASD group became slower in the Session 2. - Intact consolidation in ASD and control group. -ASD group learned less well balanced that the control group. - Participants used their implicit strategies for both explicit and implicit stimuli.

Theoretical background and conceptions of Experiment I.

The first study examined working memory in autism. ASD are characterized by inflexible, repetitive behaviour, inadaptive cognitive functioning (organization, impulse control, planning memory, attending, sustaining, initiating, emotional control, motor control, shifting, inhibition, flexibility), there is evidence that executive function deficits contribute to the core symptoms (*Baron-Cohen, Bolton*, 2000; 1997; *Rommelse et al.* 2011*; Győri,* 2012). The theory of executive dysfunction (*Ozonoff*, 1997) draws attention to the role of frontal lobes in the daily activities. Earlier examinations have found mixed evidence of working memory impairment in autism. Our goal was to get our results compared with learning abilities.

Objective and hypothesis of Experiment I.

We expected impaired performance in working memory tasks compared to the both an aged control and a mental-age control group. The objective of the present study was to get our results compared with learning abilities.

Participants and methods of Experiment I.

A total of 124 subjects, (31 children with ASD, 34 IQ-matched, and 59 age matched children) participated in the experiment. The children's IQ was measured by the MAWGYI (*Lányiné et al.*, 1996) and Raven Progressive Matrices Test (Raven, 1991). The following tests were used in our research: Digit span tests (*Jacobs*, 1887; *Racsmány et al.*, 2005), Listening span test (*Daneman and Blennerhasset*, 1984; *Janacsek, Tánczos, Mészáros and Németh*, 2009) and Counting span test (*Case, Kurland and Goldberg*, 1982). We discuss the measurements of the Experiment I. in Table 2.

Table 2. The measurements of Experiment I.

Measurement procedure	Studied function	Task	Correct answer
Digit span test	Verbal working memory	Memorize and repeat in order E.g., “7–2–9–1”	“7–2–9–1”
Listening span test	Complex working memory	True/False, memorize, repeat last words in order. E.g., “A tool that the seamstress often uses is a pair of scissors” “In the beaks of birds, there is always a lot of coffee”.	“true” “false” “scissors coffee”
Counting span test	Complex working memory	Counting all the blue dots on a card and then remember how many dots were on the cards.	The outcome of the counting.

Results of Experiment I.

The present study found intact verbal memory (on Digit span test) but impairment across two tasks (Listening span test and Counting span test), that suggests complex working memory in ASD is not intact. Our findings draw attention of the relevance to the theory of executive dysfunction (*Ozonoff*, 1997), which can explain the cognitive characteristics (impairments in organization, impulse control, planning memory, attending, sustaining, initiating, emotional control, motor control, shifting, inhibition, flexibility) of autism (*Rommelse et al.* 2011*; Győri,* 2012). Working memory capacity has an essential role in learning, and may fundamentally determine achievement in school (*Kane and Engle*, 2002; *Alloway, Gathercole, Adams, Willis, Eaglen and Lamont*, 2005; *Gathercole, Alloway, Willis* and *Adams*, 2006; *Gathercole, Pickering, Knight and Stegman*, 2004), our results may help to understand the learning difficulties in ASD.

Theoretical background and conceptions of Experiment II.

Implicit learning is defined as the acquisition of information or motor skill without conscious access to what was learned or even to the fact that learning occurred (*Shanks, St. John,* 1994). ASD is characterized by social, communicative and motor impairments (*APA*, 2013). Th autistic symptoms in activity in daily living and routine shows impairments, we need to investigate the unknown background processes (*Howling*, 2005). The semantic and episodic memories of people with autism have often been studied, but neurocognitive studies of procedural learning and implicit cognition have received less attention. The extent of learning abilities of ASD individuals is debated (*Dawson, et al.,* 2008). Previous studies showed mixed results regarding implicit sequence learning of autistic people. We examined implicit learning in ASD to probe the functional integrity of this type of fundamental learning mechanism.

Objectives and the hypothesis of Experiment II.

We expected that implicit learning is intact in the group of children living with autism compared to the control groups (age-matched and IQ-matched control). Our question was if consolidation is impaired in autism and control.

Participants and methods of the Experiment II.

We investigated probabilistic implicit sequence learning and its consolidation in ASD. Three groups of children participated: thirteen with high-functioning ASD, 14 age-matched controls, and 13 IQ-matched controls. All children with ASD were diagnosed using the criteria in the DSM-IV (*APA*, 1994) and had received clinical evaluations both according to the Autism Diagnostic Interview (ADI, *Lord et al.,* 2000) and the Autism Diagnostic Observation Schedule (ADOS, *Lord et al.,* 1994). All were tested on the Alternating Serial Reaction Time Task (ASRT), making it possible to separate general skill learning from sequence-specific learning. There were two sessions in the experiment: a learning phase (Session 1) and a testing phase (Session 2) separated by a 16-hour interval. We used a modified version of the original ASRT task (*Howard and Howard*, 1997), in which a stimulus (a dog's head) appeared in one of the four empty circles on the screen and the subject had to press a corresponding key (Y, C, B and M on Hungarian keyboard) when it occurred (*Nemeth, Janacsek, Londe, et al*., 2010). There are 6 possible sequences in which each of the four positions occurs once and only once (i.e., 1r2r3r4r, 1r2r4r3r, 1r3r4r2r, 1r3r2r4r, 1r4r2r3r, 1r4r3r2r), and each of these was used approximately equally often across subjects within a group, but the sequence for a given subject was identical during Session 1 and Session 2 (*Németh, et al.,* 2010).

Results of Experiment II.

We found that ASD children showed general skill learning and implicit learning of probabilistic sequences similar to that of two groups of controls, one matched in IQ and the other in age. In addition, the groups did not differ in consolidation; over a 16-hour period between sessions, we observed no forgetting of sequence-specific learning, as well as offline improvements in general skill, with no significant differences among groups. We believe our study to be the first to investigate implicit learning consolidation in autism (*Németh, et al*., 2010). The findings of the online learning (Session 1) are similar to those of Barnes et al. (2008) and Brown et al. (2010) who also found probabilistic implicit learning to be intact in samples of autistic children. Our results build on these earlier studies in that we show intact learning of a more difficult regularity, in that we used a 4- element ASRT task, instead of the 3-element version in Barnes et al. (2008).

Theoretical background and conceptions of Experiment III.

Our third study examined explicit learning. Higher-level cognitive functions and memory performance show deficits in autism that render more difficult explicit learning (*Johnson et al*., 2007; *Williams, Goldstein and Minshew*, 2002). Explicit learning goes on conscious way (*Baddeley*, 2001), explicit processes suffer more under circumstances with IQ impairment. If learning relies on explicit strategies, then autistic individuals could be learning less than controls due to impairments in explicit rather than implicit learning (*Németh, et al*., 2010).

Objectives and the hypothesis of Experiment III.

We expected that explicit learning is impaired in autism compared to the age- and IQ-matched control group. Our question was about consolidation and off-line learning mechanisms both in autistic and control group.

Participants and methods of Experiment III.

We investigated probabilistic implicit sequence learning and its consolidation in ASD. Two groups of children participated: 16 with high-functioning ASD, 16 age- and IQ-matched controls. All children with ASD were diagnosed using the criteria in the DSM-IV (*APA*, 1994) and had received clinical evaluations both according to the Autism Diagnostic Interview (ADI, *Lord et al*., 2000) and the Autism Diagnostic Observation Schedule (ADOS, *Lord et al.,* 1994). All were tested on the modified Alternating Serial Reaction Time Task (ASRT, *Song et al.,* 2007), making it possible to separate general skill learning from sequence-specific learning. There were two sessions in the experiment: a learning phase (Session 1) and a testing phase (Session 2) separated by a 16-hour interval. We used a modified version of the ASRT task (*Song et al.,* 2007), in which a stimulus (a dog's head) appeared in one of the four empty circles on the screen and the subject had to press a corresponding key (Y, C, B and M on Hungarian keyboard) when it occurred during the 1,2,10,11,19,20 (implicit) blocks (*Németh, Janacsek, Londe, et al.,* 2010). During the other (3.,4.,5.,6.,7.,8.,9.,12.,13.,14.,15.,16.,17. and 18.) blocks participants had to learn the sequence of the random stimuli (a razor-bill). In these explicit blocks, children could use their conscious knowledge. Each participant got their own number appertaining to sequences (i.e., 1R3R4R2R sequence means that stimuli turn up in the 1 than in the 3,4, and 2 positions, and R is random stimulus than stimuli turn up repeatedly in the same sequence during that block).

Results of experiment III.

We did not find significance in sequence learning and motor skill learning neither in the ASD nor in the control group. Participants with ASD became slower during the Session 2. We investigated intact consolidation in ASD and control group. ASD group learned less well balanced that the control group. Participants used their implicit strategies for both explicit and implicit stimuli.

Why has the current study and several others found intact implicit sequence learning in this population (*Németh et al*., 2010; *Gordon and Stark*, 2007; *Barnes et al.*, 2008) while others did not (*Mostofsky et al*., 2000)? Brown et al. (2010) has suggested that explicit strategies could affect the differences in these findings: they reason that such strategies could help in learning deterministic sequences (but not probabilistic ones, since they are more difficult to discover explicitly). Brown et al. (2010) also reason that ASD individuals are prone to solving tasks explicitly, as shown in several studies (e.g., Theory of Mind performance is mediated explicitly in ASD (*Happé*, 1995; *Hill et al*., 2004). Thus, their impairments may be reflecting impaired explicit, not implicit learning. When there is no chance to use explicit strategies, as in our study, or in Barnes' (2008) and Brown's (2010) the autistic participants are able to reveal their intact implicit learning.

DEVELOPMENT AND THERAPY OF AUTISM

The international consensus about the development of autism suggests early cognitive behavioral intervention, provides structures of the environment and activities (*Lai, et al*., 2013; *NAPC*, 2003; *Csepregi*, *Horvát and Simó*, 2011). Our findings according to others (*Barnes, et al.*, 2008; *Brown et al*., 2010) suggests that autistic children can use the effects/results of implicit learning not only for a short period but also for a longer stretch of time. Learning seems to get embedded into the cognitive system, which could play an important role in therapy. Using these results we suggest to use and develop educational and rehabilitation programs working implicitly. We attempt to submit interventions focus on structural situation/ implicit learning in Table 3.

Table 3. Interventions of autism: focuse on structural situation/ implicit learning

Interventions focused on structural situation	**Interventions focused on implicit learning**
ABA-based interventions (Applied Behavior Analysis, *Callahan et al.*, 2010)	Implicit working memory training (*Klinberg et al.*, 2010)
Lovaas-program (*Maglione et al.*, 2012)	Video self-modeling (*Love*, 2014), Training in living skills and autonomy (*Maglione et al.*, 2012)
TEACCH-program (Treatment Education of Autistic and Related Communication-Handicapped Children, *Schopler*, 1994)	Parent-mediated early intervention *(Lai, Lombardo and Baron-Cohen*, 2014)
Cognitive behavioral therapy (*Panerai et al.*, 2009)	Picture Exchange Communication System, PECS, *Maglione et al.*, 2012)
Helping Autism-diagnosed teenagers Navigating and Developing Socially (HANDS, *Mintz, Győri and Aagaard*, 2012)	Training in joint attention, pretend play, socially synchronous behavior, imitation, emotion recognition, theory of mind, and functional communication (*Lai, Lombardo and Baron-Cohen*, 2014)
STAR (*Young*, 2006)	Social intervention (for example Mindreading, The Transporters, *Maglione et al.*, 2012)
Walden Toddler Program (*McGee*, *Morrier* and *Daly*, 1999)	Sensory Integration Therapy (SIT, Ayres therapy; *Ayres*, 1979), Multisensory Integration (MSI) (*Howlin*, 2004)
	„Babzsák" program (*Öszi et al.*, 2007)
	Alternative therapy (animal assisted-, art-, hydrotherapy, *Howlin*, 2004)

Conclusions

The dissertation reports a comprehensive view of cognitive functioning, working memory, implicit, explicit learning processes, and consolidation in ASD compared to neurotypically developing control. We believe our studies to be one of the first to investigate all of these cognitive functions in ASD in Hungary.

The main results of the dissertation are 1) we showed intact verbal short-term memory (Digit span test) but impaired complex working memory (Listening span test and Counting span test) in ASD.

We found that control and ASD children showed similar implicit sequence-specific and general skill learning in the learning phase. Consolidation of implicit skill learning and sequence-specific learning were also intact in the ASD compared to the control groups.

We did not find differences in explicit sequence learning between ASD and control group. We showed intact consolidation in ASD and control group during explicit sequence learning.

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