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Working memory functions in Autism Spectrum Disorder: A review

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Keywords
Autism Spectrum Disorder, working memory, executive functions, neurodevelopmental disorder

Abstract
Autism spectrum disorder, one of the most common neurodevelopmental disorders, is a lifelong condition, especially with difficulties in social communication, limited interest, and repetitive behavior. Working memory, as a basic executive function, is a cognitive process also associated with impulse control, inhibition, organization, mental flexibility, focusing on one's attention, planning, responding to new situations, initiating and monitoring actions, problem solving, and goal-directed behaviors. Studies suggest that working memory impairments are associated with repetitive behaviors, and the risk for academic failure observed in autism spectrum disorder, and other neurodevelopmental disorders. From this point of view, working memory deficits are often found in neurodevelopmental disorders, especially in autism spectrum disorder. In the current study, following an introduction to autism and working memory, working memory functions associated with autism spectrum disorder were reviewed in detail. In this context, brain imaging studies highlighting the importance of frontal lobe functions, links between repetitive behaviors and working memory, and age differences in working memory functions were summarized. Next, working memory deficits in other neurodevelopmental disorders, such as attention deficit/hyperactivity disorder and pervasive developmental disorder were discussed in comparison with autism. Finally, the conclusion part of the current review tried to provide a contribution to future studies.

Anahtar kelimeler
Otizm Spektrum Bozukluğu, çalışma belleği, yürütücü işlevler, nörogelişimsel bozukluk

Öz

Otizm Spektrum Bozukluğunda çalışma belleği işlevleri: Derleme çalışması

En yaygın nörogelişimsel bozukluklardan biri olan otizm spektrum bozukluğu, özellikle sosyal iletişim kurmada zorluk, sınırlı ilgi ve tekrar eden davranışlarla ortaya çıkan ve yaşam boyu süren bir durumdur. Temel bir yürütücü işlev olan çalışma belleği ise aynı zamanda dürtü kontrolü, inhibisyon, organizasyon, zihinsel esneklik, dikkati odaklama, planlama, yeni durumlara cevap verme, eylemleri başlatma ve izleme, problem çözme ve hedefe yönelik davranışlarla ilişkili olan bir bilişsel işlevdir. Araştırmalar, çalışma belleği bozukluklarının otizm spektrum bozukluğunda gözlemlenen tekrarlayan davranışlar, akademik başarısızlık riski ve diğer nörogelişimsel bozukluklarla ilişkili olduğunu göstermektedir. Bu açıdan, çalışma belleği bozuklukları nörogelişimsel bozukluklarda, özellikle otizm spektrum bozukluğunda sıklıkla görülmektedir. Mevcut çalışmada, otizm ve çalışma belleğine dair giriş bölümü sunulduktan sonra, otizm spektrum bozukluğu ile ilişkili çalışma belleği fonksiyonları detaylı olarak gözden geçirilmektedir. Bu bağlamda, frontal lob fonksiyonlarının önemini vurgulayan beyin görüntüleme çalışmaları, tekrarlayan davranışlar ve çalışma belleği arasındaki bağlantı ve çalışma belleği fonksiyonlarındaki yaş farklılıkları özetlenmiştir. Daha sonra, dikkat eksikliği ve hiperaktivite bozukluğu ve yaygın gelişimsel bozukluk gibi diğer nörogelişimsel bozukluklarda çalışma belleği bozuklukları otizmle karşılaştırılarak tartışılmaktadır. Son olarak, mevcut derlemenin sonuç kısmında gelecekteki çalışmalara katkı sağlaması amaçlanan öneriler yer almaktadır.

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The term autism is derived from “autos”, the Greek word for self, and it was first used by Bleuler in 1911 to refer to the social withdrawal observed in people diagnosed with schizophrenia (as cited in Evans, 2013, p. 4). In 1943, Leo Kanner used “early infant autism” as a diagnosis for eleven children who shared a common set of behavioral characteristics. According to Kanner (1943), the two most important indicators of autism are extreme social isolation from other people and insistence on the preservation of sameness, although other indicators include reduced intellectual ability, limited imagination, an inability to use language for communication, echolalia, the misuse of pronouns, hypersensitivity to stimuli, and repetitive behaviors. Also, in 1944, Hans Asperger described a different set of indicators for autism spectrum disorder (ASD) that included an inadequacy in developing emotional reactions to others, stereotyped behaviors, special interests, and motor insufficiencies (as cited in Evans, 2013, p. 23). While Kanner and Asperger offered contemporaneous and independent descriptions of the same disorder, both identified social problems as the most important indicators of autism.

In the 1960s, Michael Rutter (1968) reviewed the diagnostic criteria for autism employed in various fields and tested the validity of the resulting cluster of symptoms. Results revealed four symptoms critical in diagnosing autism: 1) delayed language development, 2) inadequacy in establishing social relationships, 3) ritualistic and compulsive behaviors, and 4) onset before 30 months. This set of diagnostic criteria is still valid today. Today, the Diagnostic and Statistical Manual of Mental Disorders (DSM)-5 lists autism as a separate diagnostic classification under the title “Common Developmental Disorders” (American Psychiatric Association, 2013). In DSM-5, autism is described as a neurodevelopmental disorder that is characterized by repetitive behaviors and inadequacy in mutual social communication and interaction and can be observed in the early years of life.

Wing and colleagues (Wing, 1988; Wing & Attwood, 1987; Wing & Gould, 1978) proposed the term autism spectrum disorder to reflect the view that the aforementioned characteristics, including delays in language development and ritualistic and compulsive behaviors may manifest differently in different individuals. In addition, other researchers have argued that individuals with autism may exhibit different levels of functionality and that individuals with autism can achieve high levels of linguistic and cognitive development (Ameli et al., 1988; Wing, 1981). Although most children with autism (50% – 70%) have mental problems (Schopler & Mesibov, 1995; Sigman et al., 2006), some individuals meet the criteria for autism but do not exhibit mental retardation. For such individuals, the term high-functional autism is often used (Gillberg & Coleman, 2000).

Lotter began studying autism in 1966 (as cited in Evans, 2013, p.17) and research continues today. One in every 2,500 children was diagnosed with autism in 1985, 250 in every 2,500 children were diagnosed with autism in 2001, and 88 in every 2,500 children were diagnosed with autism in 2013 (Autism Speaks, n.d.). The earliest studies into the prevalence of autism found a consistent difference between genders, with boys being three to four times more likely than girls to have autism (Boat & Wu, 2015). Autism is generally associated with and described using a person’s social, linguistic, and behavioral characteristics. There are major cognitive theories proposed to describe these impairments in autism (for a review, see Rajendran & Mitchell, 2007). One of them is the theory of mind deficit, noting that people with ASD cannot interpret others' mental states such as attitudes, beliefs, desires, and emotions. Hence, they fail to make accurate mental state inferences to others, as separate to the self (Baron-Cohen, 1995). Second, the weak central coherence theory refers to the notion that people with ASD lack the ability to process information by extracting overall meaning, just the opposite, they have a tendency to process detailed parts of the information (Happé & Frith, 2006). Last, the theory of executive dysfunction, which identifies ASD in motor and cognitive aspects, states that ASD deficits are linked to executive impairments (Hill, 2004). Indeed, the present study reviews distortion of executive functions (especially working memory) experienced by individuals with autism.

Working Memory (WM)

WM is classified among executive functions, a group of functions that also include impulse control, inhibition, organization, mental flexibility, focusing one’s attention, planning, responding to novel situations, initiating and monitoring actions, problem solving, and goal-oriented behaviors (Doğan, 2016; Hill, 2004). WM is a fundamental process that, alongside cognitive functioning and executive ability, plays a crucial role in educational and academic performance (Kercood et al., 2014). It also has a great impact on daily life (Habib et al., 2019). WM allows individuals to form mental impressions by transforming information into/from different modalities. For example, it enables an individual to instantly associate an auditory code with a visual code or to merge an auditory code with an emotional code. WM can be characterized as a system that individuals use to temporarily hold and organize information while performing cognitive tasks at the same time (Baddeley & Hitch, 1974).

WM is often used interchangeably with short-term memory (STM), since both do not hold information for long: STM stores information for a short time, while WM manipulates information temporarily stored. In other words, STM merely retains information, while WM retains and uses it simultaneously. WM has three subprocesses: coding information, storing information, and choosing the best way to use information (Melton, 1963). Because long-term memory (LTM) stores information permanently, the formation of long-term memories by the WM takes long time. However, once such memories are formed, they can facilitate retention and recall, which depend on the repetition of the information. The more information is repeated, the better it is remembered. People who perform a given task frequently perform it much faster. In this sense, tasks used to measure WM require participants to simultaneously retain information in memory and to process this information. Such tasks measure the two systems of WM—the verbal system and the visual system.

Baddeley's model of WM. WM is also described as a process in which information is kept “online” to guide behavior (Baddeley, 2012). WM includes four components (Baddeley, 2012; Baddeley & Hitch, 1974): the phonological loop, the visuospatial sketchpad, the central executive, and the episodic buffer. The phonological loop is responsible for storing verbal and auditory information related to communication. It includes spoken language, meaning that it processes information obtained through communication, including written communication. The phonological loop has two components: the phonological store and the articulatory control process. The visuospatial sketchpad maintains information in terms of its visual or spatial characteristics. The central executive coordinates the actions of the phonological loop and the visuospatial sketchpad. The episodic buffer links WM with LTM. So, it acts as a bridge between WM and episodic LTM (Baddeley, 2012).

Memory systems are considered to be separate structures, and memory is a dynamic system. However, WM is the most basic memory system because it is responsible for the effective storage, access, evaluation, and transformation of cognitive activities. WM develops gradually through early and middle childhood (Huizinga et al., 2006). Processing strategies, including strategies for processing language, are all developed in WM, and they all undergo continuous development. WM benefits our daily lives, so it is essential to maintain WM over the course of our lifetimes.

Common developmental disorders like attention deficit/hyperactivity disorder (ADHD) and Tourette syndrome are comorbid with each other, both causing distortions of executive functioning, especially in WM (Barkley, 1997; Hill, 2004; Verté et al., 2006). Executive dysfunction is also observed in individuals with damage to non-frontal brain areas (Hill, 2004). Many studies suggest that autism may significantly affect executive functioning and WM (e.g. Ozonoff et al., 1991), and people with autism experience deficits in WM. These deficits are reflected as distorted thinking, problems with behavioral control and attention, including distraction and difficulty in sustaining attention. Some suggest that individuals with autism perform poorly on tests of WM because of primary or inherent deficiencies in conceptual reasoning and planning (Williams et al., 2005). On the other hand, other studies show no difference in the executive functioning and WM of autistic and non-autistic children (Dawson et al., 2002; Griffith et al., 1999). In another study, Ozonoff and Strayer (2001) have suggested that WM is not one of the most severely affected executive functions in ASD. Although there are many studies, studies have produced inconsistent findings. That remains an open problem in the area.

WM in Autism

WM deficits are considered to be among the core cognitive deficits in autism, which is characterized by difficulties in both social and non-social situations. According to Kanner (1943), people with autism are born with a limited ability to make meaningful social and emotional connections with other people. Numerous studies on WM have been conducted with children and adults diagnosed with autism according to the criteria provided by the DSM-5 (American Psychiatric Association, 2013). Over the past twenty years, however, research into the relationship between WM and ASD has produced conflicting results. Although some studies suggest that individuals with ASD have no problems with some domains of WM (Griffith et al., 1999; Ozonoff & Strayer, 2001; Russell et al., 1996), others suggest that they do Bernetto et al., 1996; Williams et al., 2005).

Studies into WM impairments show that rehearsal and repetition are essential to the development of processing speed. According to Baddeley (2000), executive functions can be seen in early years of development, and vocabulary, language processing, and language acquisition can be used as measures of memory performance. WM impairments associated with developmental disorders have important implications for learning (Alloway et al., 2009), and they can indicate deterioration in frontal lobe functions, as is seen in neurodevelopmental disorders such as Tourette syndrome, ADHD, and ASD (Lopez et al., 2005). In this regard, neuroimaging studies have also been conducted into autism, though most have tested the hypothesis that autism and frontal lobe damage affect the same brain areas and cause similar neuropsychological disorders. Some of these studies found that children with autism got lower scores on tasks measuring executive functions and frontal lobe functions (Ha et al., 2015). Barendse and colleagues (2013) assembled a comprehensive review of articles suggesting that findings from neuropsychological tests and neuroimaging techniques correlate with WM deficits in adolescents with high functioning ASD. Studies suggest that deficits in WM indicate deficiencies in frontal lobe functions. A recent longitudinal study by Vogan and colleagues (2019) examined functional changes associated with WM in children with autism. Participants were followed up two years later and researchers used functional magnetic resonance imaging to determine if children with autism showed evidence of greater WM load than did typically developing children. They found that typically developing children showed greater activation over time in their frontal, parietal, and occipital lobes than did children with ASD. Children with ASD also showed greater load-dependent deactivation over time in their default mode networks than did typically developing children (Vogan et al., 2019).

Along with the neuroimaging findings, behavioral data from several studies have generally shown that people with ASD get significantly lower scores on WM tests, measuring the verbal system (Bennetto et al., 1996) and the visual system (Williams et al., 2005) separately. Several of these studies used classic measurements of planning and problem solving, which are the Hanoi Tower (Simon, 1975) and the London Tower task (Shallice, 1982) to measure specific domains of WM and found that individuals with high-functioning autism got lower scores than did participants of a control group (Bennetto et al., 1996; Ozonoff et al., 1991). It has been suggested that WM is seriously impaired in autism. Zhang and colleagues (2020) reported a significant difference between the ASD and typically developing control groups, which indicated remarkable spatial WM impairments in ASD, concluding that spatial WM may be a core cognitive characteristic of ASD. WM deficits have been further explored in individuals with ASD, their unaffected siblings, and typically developing controls by assessing verbal and visuospatial WM. For example, Seng and colleagues (2020) reported poorer verbal and visuospatial WM in participants with ASD, relative to healthy controls. Of note, the sibling group did not differ from the ASD group, reflecting verbal and visuospatial WM impairments in unaffected siblings of ASD compared to healthy controls. This finding suggested verbal and visuospatial WM as potential cognitive endophenotypes for ASD (Seng et al., 2020). On the other hand, Ozonoff and Strayer (2001) argue that WM is a part of the brain's executive function and that measures of WM employed by previous studies—including Running Memory Span tasks and Spatial Memory Span tasks—are appropriate for measuring executive functions. For this reason, they measured WM using specific tasks, including a Running Memory Span task, a Spatial Memory Span task (participants were asked to recall the location of three to five geometric shapes on a computer screen), and a Box-Search task (participants were asked to find hidden objects behind colored boxes by simultaneously keeping the boxes' color in WM during the search.). They measured WM performance across three groups: participants with autism, participants with Tourette syndrome, and a control group. They found no significant differences among three groups, though WM performance was found to be correlated with both age and intelligence score (Ozonoff & Strayer, 2001).

The results of Gilotty and colleagues (2002) contradict those of Ozonoff and Strayer (2001). Gilotty and colleagues (2002) investigated the relationship between executive function and adaptive behaviors in individuals with high-functioning autism and individuals with Asperger syndrome. The Vineland Adaptive Behavior Scales were used to measure adaptive behaviors, and the parent-rating form of the Behavior Rating Inventory of Executive Function was used to measure WM function. Findings revealed that adaptive behaviors and WM were negatively correlated (Gilotty et al., 2002), suggesting that subdomains of adaptive behavior, such as social abilities and communication, were observed in ASD and these distortions were related to WM (Gilotty et al., 2002). Gilotty and colleagues (2002) also compared different domains of WM functions in children with Asperger syndrome and children without Asperger syndrome. They employed six WM Span tasks. Two tasks measured verbal storage (phonological loop)—a digit recall task and word list recall task—and two tasks measured complex memory: a memory span task and a backward digit recall task. They also employed a counting recall task to measure central executive functions (processing and storing). The final two tasks measured visuospatial sketchpad function:

a block recall task and a variant-visual-pattern task. Results revealed that children with Asperger syndrome performed better than the control group on the tasks that required phonological-loop storing but that they performed worse than children without Asperger syndrome on the visuospatial WM tasks (Cui et al., 2010). These results suggest that individuals with ASD could have partial deficits in central executive functions.

Dual tasks, which require individuals to perform two tasks at the same time, are used to measure WM. Garcia-Villamistar and Della Sala (2002) have predicted that dual-task performance is impaired in individuals with autism because multitasking is positively related to executive functions, especially WM. Garcia-Villamistar and Della Sala (2002) used a dual-task paradigm to compare WM performance of adults with autism and adults without autism, requiring participants to perform a tracking task and a digit recall task simultaneously. They used the tracking task and the digit recall task separately in single-task conditions. Their results agreed with those of previous studies, revealing that while participants performed similarly in the single-task conditions, adults with autism got significantly lower scores in the dual-task condition than did adults without autism. Nevertheless, more research studying dual-task paradigms in people with ASD are needed.

Along with all these studies, Habib and colleagues (2019) conducted a meta-analysis to examine the WM impairments in people with ASD. In their analysis by systematically reviewing 29 articles containing 34 studies, they especially focused on the WM deterioration in terms of phonological and visuospatial domains. Studies that did not have a matched control groups on age and intelligence quotient (IQ) were not included. According to results, individuals with ASD had significantly lower scores in the tests measuring the phonological and visuospatial domains compared to those who typically developed, suggesting that there was a greater impairment in both phonological and visuospatial domains in people with ASD. As possible moderators of WM impairments in people with ASD, researchers also considered age and IQ in their systematic review and meta-analysis to determine whether these impairments in WM were reliable across different age and IQ groups. However, the effects of these sample characteristics on the effect sizes were not found to be significant, indicating that these WM impairments were not associated with age or IQ in individuals with ASD (Habib et al., 2019). These results suggest that individuals with ASD have significantly impaired WM test performances that were not moderated by age and IQ, although some studies have concluded that visuo-spatial WM is more impaired than verbal WM (for the meta-analysis study, see Xie et al., 2020).

In another WM and ASD meta-analysis study, including a total of 29 studies using tasks such as Digit Span, Forward and Backward Block Span, and Spatial Working Memory, researchers found that individuals with autism had significant verbal and spatial WM impairments compared with a matched group of typically developing controls, but they emphasized that this was not related to intelligence (Wang et al., 2017). Another recent meta-analysis study conducted by Lai and colleagues (2017) concluded that deficits in all components of executive function, including spatial and verbal WM, were found in children and adolescents with high-functioning ASD. This is consistent with a recent study in which Letter-Number Sequencing and Digit Span Backward Subtests of the Wechsler Intelligence Scale for Children (WISC)-IV were used to assess verbal WM performance (Rabiee et al., 2020). Researchers reported that children with high-functioning ASD had a poorer performance in tasks assessing verbal WM, compared with controls. In the light of reported findings, it is conceivable that the impairment of WM is evident in individuals with high-functioning ASD.

On the contrary, there are findings different from the aforementioned meta-analysis and research studies examining the performance on WM in ASD (Rabiee et al., 2020; Van Eylen et al., 2015). Specifically, Rabiee and colleagues (2020) found no significant differences between participants with ASD and controls in visuospatial WM tasks. Similarly, after controlling for possible confounding variables, Van Eylen and colleagues (2015) reported no significant differences between participants with ASD and typically developing individuals in backward and forward Spatial Span tests measuring spatial WM. Van Eylen and colleagues (2015) also used the Spatial Working Memory test from the Cambridge Neuropsychological Test Automated Battery (CANTAB) (Happé et al., 2006; Landa & Goldberg, 2005; Sinzig et al., 2008), and findings showed that impairments were only observed for the most difficult conditions. This finding points to subtle working memory problems yet concluding that differences in task characteristics might lead to inconsistencies in WM and ASD literature.

As described above, results obtained in ASD and WM studies have been inconsistent. One possible reason for these inconsistencies could be the influence of potential confounding factors, such as comorbidity. For example, whether comorbid ADHD is excluded may explain the mixed findings. Type and degree of WM dysfunction in people with ASD also depends on other variables, such as the assessment tools to measure WM and criteria for diagnosis. Previous studies on WM in ASD reported mixed findings; this could be due to different neuropsychological tasks employed in studies (Van Eylen et al., 2015); accordingly, task difficulty might be another issue for future research to explore. Moreover, differences in sample characteristics might cause inconsistencies; so, this confound should be addressed controlling for important covariates such as IQ, gender, and age. Potential moderating variables should be examined in future studies.

Restrictive and Repetitive Behaviors and WM

Restricted and repetitive behaviors are one of the main diagnostic features of ASD. Although repetitive behaviors such as kicking, clapping, and shaking are observed in typically developing children in the first years of life, these features disappear before ages three and four years old. On the other hand, stereotypes seen in children diagnosed with ASD increase in the first five years. In these children, swinging, turning, tiptoe walking, flapping wings, repetitive games with non-functional objects, lack of interest in typical toys and games, and being busy with more than one object are common (Ghaziuddin, 2005). Studies show thatrepetitive behaviors of individuals with ASD are related to WM deficits (Lopez et al., 2005; South et al., 2007; Van Eylen et al., 2015). In other words, the inability to control actions causes the frequency of repetitive behaviors to increase (Joseph, 1999; Sayers et al., 2011).

WM is significantly related to the repetitive and restrictive behaviors exhibited by individuals with autism. Accordingly, repetitive behaviors can be observed due to poor WM performance. Lopez and colleagues (2005) compared the executive functioning (including WM) of adults who were suffering from autism and adults who were not. In doing so, they employed a variety of measures of restrictive and repetitive behaviors, including the Autism Diagnostic Observation Schedule, the Autism Diagnostic Interview-Revised, the Gilliam Autism Rating Scale, and the Aberrant Behavior Checklist. They also performed intellectual and neuropsychological assessments using the WISC-III, the Wisconsin Card Sorting Test (WCST) (Dichter et al., 2010), and several subtests from the Delis-Kaplin Executive Function Scales, including the California Verbal Fluency Test. Their results showed that individuals with low scores for executive processes (including WM) were significantly more likely to exhibit repetitive behaviors associated with ASD, while other executive functions, including planning and fluency, were not found to be associated with repetitive symptoms (Lopez et al., 2005). Similarly, Van Eylen and colleagues (2015) found that greater severity of restricted behaviors (assessed by the Repetitive Behavior Scale-Revised) was associated with poorer WM performance.

Although much of the previous work reported that WM deficits were positively related to restricted/stereotyped behavior severity, other research did not report a link between repetitive behaviors and WM dysfunction (Rabiee et al., 2020; Seng et al., 2020). For example, in a recent study by Rabiee and colleagues (2020), WM performance and its relationship with symptoms of ASD were investigated. The Gilliam Autism Rating Scale-Second Edition (GARS-2) was used to measure stereotyped behaviors. Interestingly, performances on Visual Digit Span and Digit Span Forward WM tasks were positively correlated with the stereotyped behavior subscale of GARS-2. Similarly, Seng and colleagues (2020) found that the severity of restricted/stereotyped behaviors in ASD was not significantly associated with either verbal or spatial WM dysfunctions. Researches have yet to fully support a relationship between WM and restrictive and repetitive behaviors, and future research should be devoted to this topic.

Besides, differences in repetitive behaviors measured in studies might lead to inconsistent findings. Lopez and colleagues (2005) indicated that WM deficits were associated with higher-order repetitive behaviors, such as compulsions and rituals. On the other hand, a correlation between lower-order motor repetitive behaviors (such as stereotypy and self-injury) and WM has also been documented in the literature (Lemonda et al., 2012), revealing that lower performance of individuals with ASD in WCST predicted greater frequencies and longer durations of stereotypies. Further research is required to explore how lower and higher-order repetitive behaviors are linked to different domains of WM.

Age Differences in ASD

A broad body of research on aging in normal developing adults has shown that various cognitive processes decline with aging; however, little is known about WM functions in elderly with autism. Although autism is a life-long disorder, research has focused mainly on children (Cui et al., 2010; Gilotty et al., 2002). In a study of Williams and colleagues (2005), in contrast, they used a variety of tests to examine verbal and spatial WM in high-functioning autistic children/adolescents and adults compared to age-matched controls. To measure verbal WM, they used the Wide Range Assessment of Memory and Learning (WRAML), the Letter-Number Sequencing Subtest of the Wechsler Memory Scale-III (WMS-III), and the N-back Letter Task. To measure spatial WM, they used the WRAML Finger Windows Subtest for children and the WMS-III Spatial Span Subtest for adults. They found a significant difference in spatial WM between the autism and control groups in both age ranges, but no difference between the autism and control groups on the verbal WM tasks. In other words, the children/adolescents and adults with ASD performed poorer as compared to the controls in spatial WM tasks. Since no deficit in verbal WM was reported, these results did not support the notion that deficits in verbal WM are the root of the deficits in planning exhibited by individuals with ASD.

Geurts and Vissers (2011) compared the WM performance of high-functioning autistic adults and adults without autism as a function of age (participants ranged from 51 to 83 years old). Researchers first used the Social Responsiveness Scale to confirm diagnoses of autism. Then, they used the Dutch Adult Reading Test to assess verbal intelligence, the Processing Speed Task (a subtest of the WISC-III) to assess information processing, the Sustained Attention to Response Test to assess attention, the Spatial Span WISC-III Subtest to assess visuospatial WM, the Trail Making Test and the modified Card Sorting Test to assess cognitive flexibility, the Tower of London Test to assess planning, the Controlled Word Association Task to assess verbal letter fluency, the Visual Reproduction Subtest of the WMS-III to assess visual memory, and the Dutch version of the Rey Auditory Verbal Learning Task to assess verbal memory. Results revealed that participants with high-functioning autism experienced more difficulty with sustained attention, WM, and fluency tasks than did the age-matched control group. However, the elderly with autism did not show impairments in other cognitive domains when compared to the control. Similarly, Wang and colleagues (2017) emphasized that significant WM impairments in individuals with autism were not related to age. These results might suggest that with increasing age the deficits reported at young age disappear.

Using Positive Reinforcement to Facilitate WM in ASD

Individuals perform many WM tasks in their daily lives. School-aged children use their WM when reading, solving problems, or writing, so WM is understandably related to education performance. Alloway and Gathercole (2006) emphasized that WM is an essential factor in learning and storing information. They also highlighted the importance of early intervention methods for children diagnosed with learning disabilities with WM impairment since children with low WM capacity have difficulty in learning and they often fail (Alloway & Gathercole, 2006). However, a limited number of studies have evaluated WM training in students with ASD. Baltruschat and colleagues (2011a) investigated whether positive reinforcement procedure affected performance on the counting span task, which is mostly used to measure the central executive component of WM. In doing so, they compared children with ASD and a control group without ASD. Children were also asked to complete six measures of WM: complex span, color span, digit span backwards, Stroop-like, go/no-go, and the computerized version of counting span tasks. They re-developed the counting span subtest with the same difficulty but with different stimuli, changing the colors and shapes. Baltruschat and colleagues (2011a) presented the stimuli to the participants as 17 green shapes on white background flashcards with a number and asked to count silently the number of ovals featured on the flashcard and say the counted quantity out loud to the experimenter. Results revealed that positive reinforcement improves WM performance in children with ASD. Further analysis of the effects of positive reinforcement on WM in children with autism was conducted by Baltruschat and colleagues (2011b). The extended study is a use of the same procedure, positive reinforcement, to measure WM, a complex span, with additional three children with ASD. They added novel pictures to instead of the colors and shapes flashcards. Eight flashcards consisting of two syllables, half of which were edible and half of which were non-edible, were shown to the participants. After each flashcard, distracting questions were asked (i.e., "can you eat it? / can you wear it?") and participants required to answer yes, or no. Correct responsiveness increased after positive reinforcement that given after the participants' answers. Results showed improved performance after positive reinforcement that given after the participants' answers even when the tasks were more complicated.

WM Deficits in Autism Compared to Other Neurodevelopmental Disorders

As previously mentioned, individuals with neurodevelopmental disorders share some common symptoms, and studies about neurodevelopmental disorders and deficiencies in WM yield similar results. For instance, people with poor WM also exhibit deficits in attention and impulsivity (Holmes et al., 2014; Sinzig et al., 2008). In two experiments, Russell and colleagues (1996) also examined individuals with autism and individuals with moderate learning disabilities. The first experiment used the British Picture Vocabulary Scale to assess the participants' verbal abilities, and the second experiment used three tasks (including counting and recall tasks) to assess the central executive function of WM. The first experiment found similar results for people with autism and typically developing people. The second experiment found that the participants with autism experienced a greater difficulty with the WM tasks than did the typically developing participants.

Sinzig and colleagues (2008) compared children with both ASD and ADHD, children with only ASD, and children developing typically. They used go/no-go task to measure inhibitory control, intra-dimensional/extra-dimensional shift (ID/ED) task to measure flexibility, the Stroop Task to measure spatial WM, and Stockings of Cambridge, a computerized test based on the London Tower Task, to measure planning. They found that children with both ASD and ADHD had more difficulty in inhibitory performance. Not only children with only ASD and children with both ASD and ADHD needed more time to complete the WM task, but also children with only ASD made more errors than did the control group. In a similar study, Happé and colleagues (2006) compared the executive functioning of children with ASD, children with ADHD, and typically developing children. All groups completed the same WM tasks, which were go/no-go task, cognitive estimates test, verbal fluency, design fluency, ID/ED task, Stockings of Cambridge, and Spatial WM from the CANTAB (Happé et al., 2006; Landa & Goldberg, 2005; Sinzig et al., 2008). In general, the CANTAB includes 22 tests and uses computerized tasks to measure various areas of cognitive functions including WM, learning and memory, visual memory, visual attention, sustained attention, planning, set-shifting, and fluid intelligence. In each task, participants are asked to tick boxes on a screen and to fill in an empty column with the correct boxes. According to results, both ASD and ADHD group performed poorer than typically developing children in all tasks. The ADHD group showed greater inhibitory problems on a go/no-go task, while the ASD group was significantly worse on response selection/monitoring in a cognitive estimates task. Goldberg and colleagues (2005) also studied with a group of children with ASD and a group of children with ADHD. They noted WM deficits in both groups.

Geurts and colleagues (2004) compared the executive functioning (including the visual WM) of children with ADHD, children with high-functioning autism, children with oppositional defiant disorder, and typically developing children. They used the Self-Ordered Pointing Test (SOPT) (Petrides & Milner, 1982) to measure visuospatial WM, and the WCST to measure WM functions in general. The SOPT measures visual WM by asking participants to respond to an array of familiar objects. Children with high functioning autism got lower scores on the planning and cognitive flexibility tests than did children with ADHD. However, children with autism did not perform differently than did children in other groups on WM tasks. Noterdaeme and colleagues (2001) compared the executive functioning (including WM and attention) of children with autism, children with language-specific disorders, and typically developing children. They used the go/no-go task to measure executive functioning but responding correctly also required WM skills. Findings revealed executive dysfunctions in both children with autism and children with language impairment. These findings suggest that both clinical groups are challenged by executive functions. While the language impaired children performed poorer than the autistic children on attentional tasks requiring WM, autistic children performed equally with the controls in terms of attentional tasks.

Scheirs and Timmers (2009) used the WISC-III to compare the WM of individuals with pervasive developmental disorder-not otherwise specified (PDD-NOS) and individuals with ADHD. Results revealed that individuals with PDD-NOS performed better than did individuals with ADHD on the WM task and the Digit Span Subtest of the WISC-III. The PDD-NOS group also got higher scores than did ADHD group on the Maze subtest, a measure of visuospatial WM.

Alloway and colleagues (2016) compared cognitive abilities of three different groups of children: children with ASD, children with Intellectual Disability (ID), and children with Speech and Language Impairment (SLI). They measured intelligence using the WMS-III, and they measured visual and verbal WM using 12 tasks from the automated WM assessment. Results pointed out that while the SLI group performed as age expected, the ASD group and the ID group demonstrated deficits in visuospatial WM. They also revealed that the ASD group, the ID group, and the SLI group all demonstrated deficiencies in verbal WM, although results did not differ significantly between them. In sum, although individuals with neurodevelopmental disorders show deficits in WM, people with autism show significantly greater deficiencies than do individuals with other disorders.

Conclusion and Further Suggestions

People with ASD show deficits relative to typically developing people in complex tasks, dual-task paradigms, and tasks that require cognitive flexibility, planning, highly functional WM, and extended WM. Although WM deficits are common in most types of neurodevelopmental disorders, individuals with ASD experience greater difficulties in WM tests. In addition, deficits in WM, and especially in verbal WM, correlate with restrictive and repetitive behaviors. However, people with ASD demonstrate nearly age-appropriate development in articulatory rehearsal, a critical component of verbal WM. Results also suggest that WM performance among people with ASD depends to large extent on task structure. It is known that WM deficits affect academic performance, but additional research is needed into WM tasks, including problem solving, listening, comprehending, and assessing verbal implications. Besides, although research on WM impairments in individuals with autism has yielded contradictory results, a review by Kercood et al. (2014) suggests that these conflicts may have resulted from different intelligence scores and different levels of linguistic ability among the participants. However, most of the studies considered in this paper controlled for these variables. Difficulty of tasks should be adjusted based on the participants, and it is important to note that many studies into autism include those with high functioning autism or with Asperger syndrome.

In sum, recent literature points to a relationship between WM deficits and deficiencies in social function, adaptive behavior, and educational success. WM deficits also correlate with restrictive and repetitive behaviors and with age differences among those with ASD. Because adults with ASD have been found to score better in cognitive flexibility and planning than do children with ASD, future studies should investigate whether differences in educational training correlate with differences in WM. Future studies should also focus on WM in the fields of education and behavioral studies. Baltruschat and colleagues (2011a) was the first to study about applying a treatment on WM, and future studies should use various measures (e.g. the Stroop task) to describe the basic components of WM (e.g. the phonological loop). Furthermore, studies on early intervention methods should be conducted to improve WM in individuals with ASD.

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