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Executive Functions in Older Adults With Autism Spectrum Disorder: Objective Performance and Subjective Complaints

Roeliena C. D. Davids¹ · Yvonne Groen² · Ina J. Berg³ · Oliver M. Tucha² · Ingrid D. C. van Balkom^{1,3}

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Abstract Although deficits in Executive Functioning (EF) are reported frequently in young individuals with Autism Spectrum Disorders (ASD), they remain relatively unexplored later in life (>50 years). We studied objective performance on EF measures (Tower of London, Zoo map, phonetic/semantic fluency) as well as subjective complaints (self- and proxy reported BRIEF) in 36 ASD and 36 typically developed individuals ($n = 72$). High functioning older adults with ASD reported EF-impairments in metacognition, but did not deviate in EF task performance, except for a longer execution time of the Tower of London. The need for additional time to complete daily tasks may contribute to impairments in daily life and may be correlated to a higher level of experienced EF-difficulties in ASD.

Keywords Autism spectrum disorder · Neuropsychological assessment · Cognition · Executive function · Processing speed · Aging

Introduction

Individuals with Autism Spectrum Disorders (ASD) often experience problems in tasks and social situations in daily living. Studies have shown that a majority of adult individuals with ASD remain dependent on others on several domains of daily life (Howlin et al. 2004, 2013; Magiati et al. 2014; van Heijst and Geurts 2014). In children with ASD deficits in executive functioning (EF) have been linked to impairments in social behaviour, and to increasing adaptive behaviour skill deficits, which persist into adolescence (Kenworthy et al. 2008, 2014; Pugliese et al. 2014). In adults with ASD, EF-deficits are related to reduced adaptive functioning, co-morbid depression and anxiety (Wallace et al. 2016). In improving adaptive functioning skills in individuals with ASD it is therefore important to examine whether individuals with ASD have EF-deficits and how these contribute to impairments in daily living. Studies on cognition in ASD have mainly focused on children and young adults, whereas ASD also affects daily functioning in older adults (James et al. 2006; Hagberg et al. 2013; Howlin et al. 2004; Mukaetova-Ladinska et al. 2012). To date, it remains unclear how aging affects EF in older adults with ASD (≥ 50 years), whether EF-impairments seen at a younger age persist over time, and how these relate to difficulties in daily life (Geurts and Vissers 2012). Therefore the aim of this study was to contribute to the understanding of executive functioning in older adults with ASD by means of objective as well as subjective measures of Executive Functions (EFs).

Studies on EF in children and young adults with ASD point primarily to an impaired flexibility in thinking, planning and acting as well as in shifting attention (Geurts et al. 2004; Granader et al. 2014; Landa and Goldberg 2005; Kenworthy et al. 2008; Rosenthal et al. 2013;

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Wallace et al. 2016; Wilson et al. 2014). While the core characteristics of ASD are in the social domain, the Executive-Function Theory proposes that difficulties with EF underlie the restricted adaptive skills of individuals with ASD (Hill 2004; Pennington and Ozonoff 1996). Indeed, deficits in working memory, initiation, shifting, planning and organizing have been reported in children with ASD and cognitive shifting in young adults with ASD was found to be related to lower quality of life, especially in academic and social functioning (Berger et al. 2003; de Vries and Geurts 2015; Pugliese et al. 2014). In a study of EF functioning in real life as measured by means of the Behaviour Rating Inventory of Executive Function (BRIEF; Gioia et al. 2000a), Rosenthal et al. (2013) found worsening scores with increasing age in children with ASD compared to typically developing (TD) controls.

Deficits in EFs on classic neuropsychological tasks like the Tower of London (ToL), Wisconsin Card Sorting Test (WCST) or verbal fluency tests have frequently been replicated in studies on children with ASD (Geurts et al. 2004; Hill 2004; Ozonoff et al. 2005). While EF-deficits on these classic tests were less consistently replicated in (young) adults with ASD, deficient EF performance in adults with ASD was found on real life EF-measures such as the BRIEF and more ecologically valid EF tests including Behavioural Assessment of the Dysexecutive Syndrome (BADS; Wilson et al. 1996; Ambery et al. 2006; Hill and Bird 2006; 2004; Pugliese et al. 2016; Wallace et al. 2016).

Neurotypical development of EF varies over the lifespan. It is related to the maturation of the brain (in particular the prefrontal cortex) and shows several growth spurts through childhood until early adulthood (De Luca and Leventer 2008). These skills begin to decline in later adulthood, again associated with anatomical changes in the brain (Albinet et al. 2012; Baudouin et al. 2009; Hull et al. 2008; Jurado and Rosselli 2007; Span et al. 2004; Salthouse 2010a, b). In addition to anatomical changes, physical functioning, psychiatric disorders (e.g. depression) and brain damage (e.g. as a result of brain injury or substance abuse) also affect EF (Desjardins-Crépeau et al. 2014; Lockwood et al. 2002). Furthermore, the age at which EFs declining differs between EF domains. For example, set shifting and verbal fluency start declining only after age 70 in typically functioning adults, whereas the decline of inhibition of irrelevant information starts declining earlier. Variables that may underlie age related differences on EF tasks are (decline of) information processing speed or psychomotor speed, task complexity, and familiarity with a task (Andrés and Van der Linden 2000; Jurado and Rosselli 2007). The complexity of a task depends on the task load (for example the amount of information to be stored,

manipulated or processed) within a specific time frame (Williams et al. 2015). It also depends on how many cognitive domains have to be simultaneously active during a task (for example auditory and visual information processing, motoric execution, memory storage, executive functioning).

Several studies compared high-functioning adults with ASD (HFA), with ages ranging from 19 to 67 years, to typically developing individuals or individuals with other neurodevelopment disorders with regard to EF (Ambery et al. 2006; Boucher et al. 2005; Bramham et al. 2009; Hill and Bird 2006; Kretschmer et al. 2014; Nydén et al. 2010a, b; Spek et al. 2011; Towgood et al. 2009). No significant group differences or differentiation from the norm group were found with regard to planning, rule learning, impulsivity, verbal or visual attention. Inconsistent results were found concerning verbal fluency; in one study the ASD group produced fewer words than TD controls, which was not confirmed in another study (Ambery et al. 2006; Nydén et al. 2010a, b; Towgood et al. 2009).

The impaired performance on cognitive tests seen both in childhood and in (late) adulthood in individuals with ASD may be explained by a specific cognitive deficit or by global slowness in motor or visual information processing, which could be attributed to a different processing 'style' (Oliveras-Rentas et al. 2012; Ozonoff et al. 2004; Towgood et al. 2009). In addition, the processes observed in normal aging (Salthouse 1996; West 1996) will also affect functioning in ASD and may therefore worsen pre-existing impairments. Alternatively, such processes may create (extra or comorbid) impairments, just as is the case in typically developing individuals. Two studies on adults with HFA provide evidence for impaired processing/motor speed and reaction time variability compared to matched TD controls (Nydén et al. 2010a, b; Towgood et al. 2009). If the complaints experienced by individuals with ASD are not restricted to EF, reduced processing speed in ASD could underlie their difficulty performing complex tasks (Spek et al. 2011).

Despite an extensive literature search, we identified only one study examining EFs in older adults with and without ASD (age range 51–83 years). This study compared both groups on various neuropsychological tests to determine which cognitive deficits are present in older adults with HFA (Geurts and Vissers 2012). The TD group performed significantly better on a visual working memory test, letter fluency and an inhibition-measure (commission errors in a sustained attention test) than the ASD group, but not on other measures of EFs (e.g. task demanding on planning, cognitive flexibility). This indicates that the deficits in planning and cognitive flexibility previously observed in

children with ASD (Hill 2004) could not be confirmed in older adults with ASD. According to the author this may suggest that these EF-deficits disappear with age. They also concluded that developmental trajectories for fluency and visual memory differ between older adults with and without HFA.

EFs can be assessed both by means of objective measures in a neuropsychological assessment and by means of self-report questionnaires determining subjective complaints in daily life. Neuropsychological tests do not always sufficiently reflect everyday life nor can all patients adequately evaluate their own cognitive impairment. Using the Dutch translation of the Autism Spectrum Quotient self-report (AQ, Baron-Cohen et al. 2001) Ketelaars et al. (2008) found only a relatively small percentage of adults with HFA in their study sample reported ASD symptoms in the clinical range. Mild ASD symptoms in the examined HFA group or limited insight into their own deficits may underlie the low self-report scores (Bishop and Seltzer 2012; Ketelaars et al. 2008). However, in other studies comparing results of self-reports to those of neuropsychological tasks, stronger associations were found between self-reports and ASD symptomatology than between neuropsychological measures and ASD symptomatology (Spek et al. 2011). Assessments and questionnaires provide distinct types of information that often do not correlate because of methodological differences, but both types are important for clinical practice. Combining subjective and objective measures can clarify complaints as reported by the caregiver or family, as well as the patient's own awareness of executive (dys)functioning and the ability to participate in society (Chan et al. 2008; Fuermaier et al. 2015; Koerts et al. 2012; Lezak et al. 2012).

The aim of the present study was to determine whether older adults with ASD, compared to matched TD controls, show impairments in executive functions as measured by both objective neuropsychological tests as well as by self-reports about their complaints in daily life. In accordance with the EF theory of autism we would expect older adults with ASD to show more difficulties in the EF domain compared to matched TD controls, in particular with increasing complexity. Based on recent findings from adolescents and adults with ASD we do not expect difficulties in task execution on objective neuropsychological tests but we do, however, expect difficulties on real life EF-measures, especially regarding metacognition and cognitive flexibility (Hill and Bird 2006; Pugliese et al. 2016; Wallace et al. 2016). Furthermore, we explored to what extent self- and proxy-reports of EFs agree, to what extent objective and subjective EF measures are associated, and how individual differences in age and processing speed influence these variables.

Methods

Participants

This study included 36 older adults (30 males, 6 females) in the age of 50–84 with an ASD diagnosis (individuals with ASD) and 36 typically developing older adults (TD controls) aged 50–79 years. All participants in the study gave written informed consent prior to inclusion. This study was approved by the Ethical Committee of the Department of Psychology at the regional University. All procedures performed were in accordance with ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

TD controls ($n = 36$) were recruited through an advertisement in local newspapers and education settings, as well as by directly approaching eligible participants from the researchers' work or family networks. Individuals with ASD were recruited at an outpatient clinic for ASD. In the database of the outpatient clinic, 118 patients were eligible due to their age (≥ 50 years) and were subsequently informed and invited by letter to take part in the study. They were requested to return a response form to decline or accept participation. Forty patients responded by returning the response form or by email. Of these forty patients, two patients declined because of the assumed burden of the assessment and one declined because the patient did not agree with the diagnosis. One patient was excluded after the neuropsychological assessment, because of a suspected degenerative disorder (which was later clinically confirmed in a specialized outpatient clinic). Eventually 36 individuals with ASD were included.

All individuals with ASD had a clinical diagnosis of ASD according to the DSM-IV or DSM-5 criteria (American Psychiatric Association (APA) 2000, 2013). The included diagnoses comprised ASD, PDD-NOS or Asperger Syndrome. All patients had been older than 30 years of age at the time of their first diagnosis. All but one diagnoses were established by a multidisciplinary team of autism experts (psychiatrists, psychologists) of the outpatient clinic for individuals with ASD. This one diagnosis was made by a psychologist for the elderly who was trained to diagnose autism. In addition to the standard assessment by anamnestic and hetero-anamnestic (semi-structured) interview, other assessment tools used were the Autism Diagnostic Observation Scale (ADOS) (Bastiaansen et al. 2011; Lord et al. 2000) and/or a semi-structured DSM-5 ASD interview.

Using a self-designed list of questions all participants were screened for sensory problems (hearing, vision) or somatic, psychiatric or neurological conditions. Participants with comorbid sensory, psychiatric, neurological or

somatic conditions were included only if neither the condition, nor the medication was expected to interfere with performance. Therefore having a (suspected) diagnosis of dementia or other degenerative disease was an exclusion criterion in this study, leading to exclusion of one of the ASD participants. None of the participants had to be excluded for hearing or vision problems. One TD control was prescribed anti-Parkinson medication for Restless Legs Syndrome and was therefore not excluded from the sample. One of the TD controls was excluded post assessment after revealing a severe psychiatric diagnosis which was expected to have interfered with performance on the assessment.

Intelligence was assessed by the Wechsler Adult Intelligence Scale-IV-NL (WAIS- IV-NL, 11 subtest, as outlined in the Materials section) (see Table 1). Participants had to be able to understand the standard instructions, therefore an impaired verbal intelligence score (defined as Verbal Comprehension Index <70) was an exclusion criterion. All participating individuals with ASD and TD controls had unimpaired VCI scores (range 74–149).

Each person with ASD was hand matched to a TD control with regard to age (± 5 years), gender and education. The groups did not differ in their level of education (see Table 1). The participants' education level was determined according to a Dutch classification system (Verhage 1964), including 7 categories: 1 = did not finish primary school; 2 = finished primary school; 3 = did not finish secondary school; 4 = finished secondary school, low level; 5 = finished secondary school, medium level; 6 = finished secondary school, highest level, and/or college degree; 7 = university degree. Many participants (individuals with ASD $n = 30$, TD controls $n = 15$)

regularly used psychotropic medication and/or medication for somatic complaints. All participants were assessed in their regular state of medication use (see Table 2) and the influence of medication use was checked (see results section).

The Social Responsiveness Scale-Adults (SRS-A) was administered to patients and a relative or partner (proxy), in order to describe the severity of their ASD symptoms and to compare ASD group scores with TD group scores. Patients as well as their proxies reported significantly higher scores on the Social Responsiveness Scale- Adults (SRS-A) than TD controls (see Table 1). When comparing SRS-A scores of self and proxy, no differences were found in the ASD group regarding the SRS-A total score, the Social Awareness (SA); Social Communication (SC); Social Motivation (SM); and Restricted Interests and Repetitive Behaviour (RR) scales. There were also no differences between the self- and proxy-scores of TD controls. Of the individuals with ASD, 13.9 % scored in the clinical range of the self-reported SRS-A, and none of the TD controls obtained a clinical score. Fifty percent of the individuals with ASD and 2.8 % of the TD controls reported mild to moderate social deficiencies on the SRS-A.

Procedure

Individuals with ASD were invited for a face-to-face neuropsychological assessment at the outpatient clinic for individuals with ASD and TD controls were invited to the Department of Psychology at the regional University. All participants were requested, by invitation letter or email, to complete two questionnaires prior to the assessment, as well as to complete the SRS-A and the BRIEF-A prior to the

Table 1 Characteristics of ASD participants and matched TD controls

	ASD ($n = 30$ males, 6 females) M (SD)	TD ($n = 30$ males, 6 females) M (SD)	Statistics
Age (years)	58.6 (7.8)	59.4 (8.3)	$d = 0.09$
Education level	5.4 (1.3)	5.9 (0.8)	$Z = -1.46$; $p = .144$
Total IQ (WAIS)	106.3 (18.4)	107.1 (15.6)	$F(1,70) = 0.04$, $p = .85$
SRS-A score self (t-score)	63.8 (10.5)	47.2(8.2)**	$F(1,71) = 55.1$, $p \leq .001$
SRS-A score proxy (t-score)	67.00 (12.92)	45.86 (6.53)**	$F(1,68) = 75.4$, $p \leq .001$
SRS-A Total self/proxy	63.8(10.5)/67.0 (10.5)	47.2 (8.2)/43.4 (7.3)	$t(1,32) = -1.13$, $p = .26$ / $t(1,35) = .96$, $p = .34$
SRS-A SA self/proxy	61.8 (11.5)/64.7 (12.8)	46.6 (9.6)/42.9 (7.3)	$t(1,32) = -0.89$, $p = .38$ / $t(1,35) = 1.60$, $p = .12$
SRS-A SC self/proxy	63.7 (10.5)/66.3 (13.7)	48.3 (8.2)/47.6 (7.2)	$t(1,32) = -0.86$, $p = .40$ / $t(1,35) = .46$, $p = .65$
SRS-A SM self/proxy	61.1 (11.5)/66.3 (13.7)	47.9 (7.6)/48.3 (8.8)	$t(1,32) = -1.70$, $p = .10$ / $t(1,35) = -.23$, $p = .82$
SRS-A RR self/proxy	63.2 (12.2)/65.7 (12.6)	46.6 (7.2)/41.3 (6.4)	$t(1,32) = -0.68$, $p = .50$ / $t(1,35) = .21$, $p = .84$

SRS-A adult social responsiveness scale; self/proxy = self-reported symptoms/proxy-reported symptoms; SA social awareness, SC social communication, SM social motivation, RR restricted interests and repetitive behaviour

* $p \leq .05$; ** $p \leq .01$; d = Cohen's d

^a Dutch education scale, ranging from 1 (elementary school not finished) to 7 (university degree)

Table 2 Regularly used medication separated for cases and controls

Psychotropic & somatic medication	Cases	Controls
Antidepressants	11	2
Benzodiazepine	1	0
Antipsychotics	0	1
Stimulants	4	0
Anti-epileptics	0	1
Anti-allergy	2	2
Anti-hypertensives	8	4
Anti-cholesterol	1	4
Anti-diabetics	1	0
Anti-parkinson	0	1
Anti-narcolepsy	1	0
Total	30	15

assessment, to invite a close relative or friend to complete these questionnaires for them as well and to bring the completed questionnaires to the assessment. A neuropsychological test battery of approximately 3 h, included tests of intelligence, EFs, speed of information processing, and memory was performed. The present study focuses on the measures of EFs only. The neuropsychological assessment had a fixed order, starting with the full WAIS-IV, followed by the EF and memory tests intersected by a break. More breaks were taken if so requested by the participant.

Materials

Social Responsiveness Scale-Adults (SRS-A)

The Social Responsiveness Scale-Adults (SRS-A) self-report version was administered to all participants, and a proxy-report variant to a relative or partner. The SRS-A is a 65 item quantitative rating scale for autistic traits and symptoms, including interpersonal behaviour, communication and repetitive/stereotypic behaviour in the past 6 months (Constantino and Todd 2005). Scores were obtained for four Treatment Subscales: Social Awareness (SA); Social Communication (SC); Social Motivation (SM); and Restricted Interests and Repetitive Behaviour (RR).

A total T-score of 76 or higher is considered a severe score. According to the SRS-A manual scores in this range are considered strongly associated with a clinical diagnosis of Autistic Disorder, Asperger's Disorder, or more severe cases of PDD-NOS. A score in this range indicates a severe interference in everyday social interactions. In most clinical settings, SRS-A T-scores at or above 76 from two separate informants provide very strong evidence of the presence of a clinically diagnosable autism spectrum disorder.

A total T-score in the range of 60–76 is considered a mild to moderate result. A score in this range indicates

clinically significant deficiencies in reciprocal social behaviour that result in mild to moderate interference in everyday social interactions. According to the SRS-A manual these scores are typical for individuals with mild or “high functioning” ASD, such as PDD-NOS, and higher functioning individuals with Asperger's Disorder.

A T-score of 59 or less is within the normal range. Typically developing individuals in the general population obtain scores within this range. When obtained in clinical settings, these scores usually suggest the absence of an autism spectrum disorder and any psychosocial dysfunction noted at referral is more likely to be due to a non-autism-related condition.

Although the validity and consistency are still under investigation, the SRS-A has performed well in a study of German participants (Bölte et al. 2008; Constantino et al. 2003; Frazier et al. 2013; Mandell et al. 2012).

Behaviour Rating Inventory of Executive Functioning-Adults (BRIEF-A)

Taking into account that neuropsychological tests of EFs do not always reflect cognitive impairments in daily life (Chaytor et al. 2006) the Dutch version of the Behaviour Rating Inventory of Executive Functioning-Adults (BRIEF-A) (Roth et al. 2005, Dutch translation Scholte and Noens 2011) was included. The BRIEF-A is a reliable instrument for the assessment of executive functioning or self-regulation in the everyday environment (Gioia et al. 2000a, b; Huizinga and Smidts 2010). The self-report version (BRIEF-A self) was administered to all participants and the observant/informant version (BRIEF-A proxy) to a close relative or partner. It is composed of 75 items with two index scales, a total scale and nine subscales. The total BRIEF score, the Global Executive Composite (GEC), is comprised of two index scales; the Behavioural Regulation Index (BRI) and the Metacognition Index (MI). The nine subscales are: Inhibition, Shifting, Emotional Control, Self-monitoring, Initiation, Working Memory, Planning/Organising, Task Monitoring and Organisation of Materials. T scores ($M = 50$, $SD = 10$) were used to interpret the individual's level of executive functioning. T-scores at or above 65 are considered to reflect clinically significant impairment.

Processing Speed Index of the Wechsler Adult Intelligence Scale-IV-NL

For the assessment of general intellectual functioning, 11 subtests of the Dutch version of the Wechsler Adult Intelligence Scale-Fourth Edition (WAIS-IV-NL) (Wechsler 2008; Wechsler, 2012) were applied. Subtests used were: Similarities, Vocabulary, Information, Block Design,

Matrix Reasoning, Visual Puzzles, Digit Span, Arithmetic, Symbol Search, Coding and Picture Completion. The dependent measure were the norm scores provided by the test authors. The processing speed index of the WAIS IV-NL (PSI) was used as a measure of speed of information processing.

Neuropsychological Test Measures of Executive Function

To measure problem solving, cognitive flexibility and planning ability, we used the German version of the Tower of London (TL-D) (Tucha and Lange 2004). In this version, participants are presented with three colored balls placed on three upright sticks of different lengths. Twenty different goal configurations are presented to the participants. They are asked to determine the order of moves necessary to rearrange the colored balls from their original position to the new set of predetermined positions. The minimum order of moves required to solve a problem ranges from 3 at the start to 6 at the end of the task, increasing the demand for planning and execution. The dependent measures were percentile scores of the number of correctly solved problems and the planning and execution time in seconds.

The Zoo Map of the *Behavioural Assessment of Dysexecutive Syndrome* (BADS) (Wilson et al. 1996) was used to assess performance on an ecologically valid task of EF. It is a paper-and-pencil test assessing planning and priority setting. The participants had to plan an effective route through a Zoo in order to visit certain sites, while abiding by restricting rules. There were two conditions, a high demand condition (Zoo map 1: unstructured) followed by a low demand condition (Zoo map 2: structured). Points were subtracted for rule breaks and lack of speed. The profile score is based on the difference in performance on the high versus the low demand condition. (Krabbendam and Kalff 1997; Lezak et al. 2012; Wilson et al. 1996). The dependent measures were the profile score and total execution time in seconds.

Executive control function, semantic memory, and divergent thinking were assessed by means of the Semantic verbal Fluency Test (category animals, 1 min) and Phonetic verbal Fluency Test (only the letter S, 1 min), which are short versions of the Dutch version of the Controlled Oral Word Association Test (COWAT) (Benton et al. 1983; Schmand et al. 2008). We used the short versions in order to reduce the length of the test battery. The number of correctly produced words within 1 min was the dependent measure for both tests.

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics 23. For testing group differences in the subjective

complaints in daily life, independent samples *t* tests were conducted on all scales of the BRIEF-A with 'group' (ASD, TD control) entered as independent samples (with α set to a conservative 0.01 for each comparison in order to adjust for multiple comparisons). Before performing this analysis, agreement between self- and proxy ratings was tested by conducting paired *t* tests and Pearson correlations for each group.

For testing group differences in the performance on neuropsychological test measures of EFs, one MANOVA was conducted on all test scores (TL-D, Zoo map, Phonetic and Semantic Fluency) with 'group' (ASD, TD control) set as the between groups factor (with α set to 0.05). In order to test a potential interaction with task complexity in the TL-D and Zoo map test, a repeated measures ANOVA was performed with 'group' (ASD, TD control) as the between groups factor and the complexity conditions as repeated measures (with α set to 0.05 for each ANOVA). The repeated measures for the TL-D were 3, 4, 5, and 6 steps, and for the Zoo map high demand and low demand). The magnitude of group differences was estimated by means of the Cohen's *d* measure for effect size. For clinical relevance it was also computed how many patients experience actual impairments on the neuropsychological EF measures, and group differences in frequency distribution of 'impaired'/'average'/'high' scores on EF measures were tested by means of a Chi square test (with α set to 0.05). Participants were considered 'impaired' if scores on problem scales were 1.5 SD or higher above the mean or if scores on skill scales were 1.5 SD or lower than the mean of the published norm groups. Zoo map scores were considered 'impaired' if the profile score was 0.

Correlations were computed to test for associations between objective and subjective measures of EFs and to test for associations between age, processing speed and the EF measures (Pearson correlations for numerical values and Spearman correlations for ordinal values). For the correlations, α was set to a conservative 0.01 in order to adjust for multiple comparisons.

To check whether the use of anti-depressant or stimulant medication affected the outcomes of this study, the group comparisons on the neuropsychological EF measures and the BRIEF-A were repeated excluding those participants using medication.

Results

BRIEF scores

When comparing the BRIEF-A scores of self and proxy, no differences were found in individuals with ASD regarding the GEC, the BRI and the MI scales (GEC: $t(1, 32) = 1.08$,

$p = .29$; BRI: $t(1, 32) = 0.56$, $p = .58$; MI: $t(1, 32) = 1.65$, $p = .11$). On the self-report questionnaire the TD group reported significantly more complaints on the MI scale than their proxies reported on this scale (MI: $t(1, 32) = 2.23$, $p = .03$), but self and proxy scores were comparable on the GEC and BRI scales (GEC: $t(1, 32) = 1.65$, $p = .11$; BRI: $t(1, 32) = 0.33$, $p = .74$). Correlations between self and proxy-report across groups were large (GEC: $r(69) = .64$, $p < .001$; BRI: $r(69) = .68$, $p < .001$; MI: $r(69) = .67$, $p < .001$). We therefore chose to analyse self-report in the remainder of this article.

Individuals with ASD reported significantly more problems on all index scores of the BRIEF-A than TD controls (GEC: $F(1, 70) = 20.9$, $p < .001$; BRI: $F(1, 70) = 22.9$, $p < .001$; MI: $F(1, 70) = 16.7$, $p < .001$), see Fig. 1. When inspecting the subscale scores, individuals with ASD differed significantly from TD controls on 6 out of 9 subscales (i.e. Shifting, Emotional Control, Self-monitoring, Initiation, Working Memory and Planning/Organising). They did not differ on the Inhibition, Task Monitor and Organization of Materials subscale ($p > .05$).

EF Performance and Execution Time

In contrast to the self-reports, no significant differences were found between individuals with ASD and TD controls on the standard outcome measures of the EF tests (including the total number of words generated during the fluency tests) ($F(5, 66) = 1.7$, $p = .14$; see Table 3). Effect sizes indicated that the differences between groups in almost all measures were of negligible to small size. However, individuals with ASD did need significantly more time to plan and execute the TL-D task. This was not the case for the Zoo map tasks. The total time of these tasks includes planning and executing time (multivariate analysis: $F(3, 68) = 3.9$, $p = .012$; Subsequent post hoc analysis: TL-D total time: $F(1, 72) = 10.4$, $p = .002$; Zoo map 1: $F(1, 71) = 1.76$, $p = .19$; Zoo map 2: $F(1, 71) = 2.21$, $p = .14$). Furthermore, we analysed whether increasing task complexity influenced performance or total execution time on the TL-D and Zoo map tasks. Both groups showed a significantly increased execution time on the TL-D with an increased task

Fig. 1 BRIEF-A self-report t-scores for cases and controls. *GEC* global executive composite, *MI* metacognition index, *BRI* behavioural regulation index. ** $p \leq 0.01$; $T \geq 65$ = score in clinical range; $T \geq 60 < 65$ = score in subclinical range

Table 3 Means and standard deviations of performance and execution time on EF tests, separated for cases and controls; effect sizes for group differences and frequencies of impaired, average and high scores are presented

Task (dependent measure)	Cases M(SD)	Controls M (SD)	Cohen's d	Cases frequencies I/A/H	Controls frequencies I/A/H
PSI	97.3 (17.05)	102.3 (15.13)	−0.31	5/26/5	2/32/2
SFT (# words)	22.1 (6.04)	25.1 (7.27)	−0.44	5/30/1	4/24/8
PFT (# words)	16.3 (7.44)	16.9 (7.19)	−0.09	Not available	Not available
Zoo map (profile score)	2.6 (1.18)	2.3 (1.22)	0.25	2 ^a /34 ^b	3/33
Zoo-1 (total time in s)	182.3 (85.03)	157.6 (71.35)	0.31	—	—
Zoo-2 (total time in s)	90.08 (99.03)	64.3 (39.04)	0.34	—	—
TL-D (percentile score)	70.3 (26.60)	64.4 (24.79)	0.23	1/25/10	0/33/3
TL-D (total time in s)	17.4 (4.27)	14.0 (4.83)	0.75**	—	—
TL-D 3 steps (total time in s)	8.5 (2.27)	6.9(1.92)	0.76	—	—
TL-D 4 steps (total time in s)	14.8 (6.35)	12.4 (5.69)	0.40	—	—
TL-D 5 steps (total time in s)	20.7 (6.67)	16.8 (5.56)	0.64	—	—
TL-D 6 steps (total time in s)	29.3 (9.73)	24.1 (11.51)	0.49	—	—

PSI WAIS-IV Processing Speed Index, PFT phonemic verbal fluency test, SFT semantic verbal fluency test; Zoo-1 BADS Zoo map 1, Zoo-2 BADS Zoo map 2, TL-D Tower of London, (total time) task execution including planning

Cohen's d: 0 < 0.2 negligible, 0.2 < d < 0.5 small, 0.5 < d < 0.8 medium, d > 0.8 large; I = Impaired (problem scales $\geq M + 1.5SD$ or skill scales $\leq M - 1.5SD$); A = Average ($M - 1.5SD < \text{value} < M + 1.5SD$); H = High (problem scales $\leq M - 1.5SD$ or skill scales $\geq M + 1.5SD$)

^a Zoo impaired profile score 0

^b Zoo not impaired profile score 1–4

Fig. 2 Completion times of the Tower of London (a) and Zoo map (b) tasks, separated for complexity, for cases and controls. Error bars represent standard errors

complexity (i.e. increased number of moves (3–6 moves) necessary to solve the problems) ($F(3, 210) = 142.7$, $p \leq .001$), but this increase did not differ between groups, $F(3, 210) = 1.4$, $p = .25$), see Fig. 2a. The same pattern (increased execution time for the high demand condition as compared to the low demand condition) was found for the different complexity conditions of the Zoo map ($F(1, 70) = 42.7$, $p \leq .001$). However, the differences were again not significant between groups ($F(1, 70) = 0.3$, $p = .59$), see Fig. 2b. The PSI index score ($\chi^2(2, N = 72) = 3.19$, $p = .20$) did not differ between groups,

although more ASD than TD participants had extreme scores (impaired or high scores). Significantly more individuals with ASD than TD controls had a very high score on the TL-D ($\chi^2(2, N = 72) = 5.87$, $p = .05$), SFT ($\chi^2(2, N = 72) = 6.22$, $p = .04$). The groups did not differ with regard to the number of individuals showing an impairment in the Zoo map ($\chi^2(1, N = 72) = .215$, $p = .63$). Since there are no norms available for the Dutch population, the number of impaired individuals per groups could not be calculated for the phonetic fluency task (letter S) (Van der Elst et al. 2006).

Table 4 Overview of correlations between subjective EF (BRIEF-A) and objective EF measures

BRIEF-A Scale/index	TL-D percentile score		BADS Zoo profile score	
	Cases	Controls	Cases	Controls
Inhibit	$r = -.410^a$	n.s.	$r_s = .347^a$	n.s.
Shift	$r = -.338^a$	n.s.	n.s.	n.s.
Behavioural regulation index (BRI)	$r = -.363^a$	n.s.	$r_s = .354^a$	n.s.
Initiate	$r = -.432^b$	n.s.	n.s.	n.s.
Working memory	$r = -.434^b$	n.s.	n.s.	n.s.
Plan/organize	$r = -.513^b$	n.s.	n.s.	n.s.
Organisation of materials	$r = -.446^b$	n.s.	n.s.	n.s.
Metacognition index (MI)	$r = -.475^b$	n.s.	n.s.	n.s.
Global executive composite (GEC)	$r = -.426^a$	n.s.	n.s.	n.s.

r Pearson's r , r_s Spearman's rho

^a Correlation is significant at the 0.05 level (2-tailed); n.s. not significant

^b Correlation is significant at the 0.01 level (2-tailed)

Table 5 Overview of significant correlations between EF task performance, age and PSI

EF measure	Age		PSI	
	Cases	Controls	Cases	Controls
PFT (#words)				$r = .449^b$
SFT (# words)	$r = -.406^a$	$r = -.488^b$		$r = .446^b$
TL-D (percentile score)				$r = .407^a$
Zoo-1 (score 0–8)	$r_s = -.367^a$	$r_s = -.423^a$		
Zoo-total (profile score)	$r_s = -.399^a$			
BRIEF-Shifting	$r = -.438^a$			
BRIEF-working memory				$r = -.374^a$

PSI WAIS-IV Processing Speed Index, PFT phonemic verbal fluency test, SFT semantic verbal fluency test, TL-D tower of London, Zoo-1 BADS Zoo map 1 (high demand); age age of participant, r Pearson's r , r_s Spearman's rho

^a Correlation is significant at the 0.05 level (2-tailed)

^b Correlation is significant at the 0.01 level (2-tailed)

Correlations Between Objective and Subjective EF Measures

Correlational analysis was performed between the self-report scores of the BRIEF-A (index and subscale scores) and the objective test scores of EFs in order to explore to what extent subjective self-reported experiences reflect objective findings (see Table 4). The expectation was that complex or high demand objective EF tasks would show a higher correlation with scores of the BRIEF-A than low demand EF tasks. Interestingly, significant correlations ($p = .01$) between the BRIEF-A and one objective measure (TL-D) were only seen in individuals with ASD. These were negative correlations between the TL-D percentile scores and the Metacognition-Index scale and MI-subscales of the BRIEF-A. No significant correlations between the BRIEF-A scores and

any of the objective EF measures were found for TD controls.

Correlational Analysis Between EF Measures, Age and PSI

Correlations were computed between PSI, age and EF task performance to explore to what extent processing speed and age influence execution time and EF task performance (Table 5). We speculated that lower PSI and higher age would be associated with increased execution times. In the TD control group PSI was significantly ($p = .01$) positively correlated with the phonetic and semantic fluency performance (PFT $r(36) = .449$, $p = .01$; SFT $r(36) = .446$, $p = .01$). Surprisingly, PSI did not significantly correlate with the execution times of the EF tests for either group. Regarding age, significant negative

correlations were found in both groups between age and semantic fluency (ASD $r(36) = -.406$, $p = .01$; TD group $r(36) = -.488$, $p = .00$).

Medication

All participants were assessed in their regular on-state of medication. An exploratory analysis of the effects of medication showed that participants using antidepressants (individuals with ASD $n = 11$, TD controls $n = 2$) reported significantly more complaints related to EF (BRIEF-A) than participants not using this medication ($F(1, 69) = 12.71$, $p = .001$) and reported significantly severe difficulties on the SRS-A ($F(1, 70) = 11.05$, $p = .001$). Participants taking stimulants (individuals with ASD $n = 4$, TD controls $n = 0$) had significantly higher scores on the BRIEF-A compared to participants not using stimulants ($F(1, 69) = 4.62$, $p = .035$). However, the above described group differences between individuals with ASD and TD controls (Tables 1, 3; Fig. 1) did not change when participants using either antidepressants or stimulants were excluded from the analysis.

Discussion

We compared older adults with ASD to TD controls on objective and subjective measures of EF, in a matched control design. We explored the effect of age, task complexity, and processing speed (time to execute a task), on task performance. Looking at neuropsychological performance measures of EFs (i.e. the TL-D, Zoo map, fluency tasks) commonly used in clinical practice, no performance deficits could be objectified. Interestingly, a larger proportion of individuals with ASD had a very high performance on the TL-D compared to TD controls (28 vs. 8 %), although as a group, individuals with ASD did not outperform TD controls. Intact TL-D performance confirms findings of a previous study on older adults with ASD on a ToL task (Geurts and Vissers 2012). Our finding of intact fluency performance, however, is inconsistent with this previous study, which revealed group differences in a phonetic fluency task, indicating that individuals with ASD had more problems in generating novel responses than TD controls. This difference in outcome may be explained by the higher task demand on the phonetic fluency task (COWAT) used by Geurts and Vissers (2012), which required participants to produce words starting with 3 different letters for a period of 1 min each (total test time of 3 min) instead of naming words starting with only one letter for a period of 1 min as performed in the present study.

With regard to the subjective complaints of EF in daily life, individuals with ASD reported significantly more EF complaints than TD controls on the majority of index- and subscales of the BRIEF-A. Impairments in cognitive flexibility were expressed on the subscale Shifting. This is in line with a previous review on the sensitivity of cognitive flexibility measures in individuals with ASD by Leung and Zakzanis (2014). In all the studies they reviewed using the BRIEF self-reports, persons with ASD showed the most impairment on the Shift subscale and also scored consistently above the clinical cut-off. Leung and Zakzanis (2014) therefore consider the BRIEF Shifting subscale as the most sensitive tool to assess differences in cognitive flexibility between persons with ASD and a typically developing control group. In our current study subclinical problem scores were reached for Planning and Organisation, Working memory and Initiation. Individuals with ASD and their relatives showed good agreement with regard to the problems with EF encountered in daily life functioning. This suggests that older patients with ASD have good insight into their difficulties with EF occurring in daily life, which indicates that the BRIEF-A is a useful clinical instrument to assess EF in this population. Additionally, convergent validity of the BRIEF-A in older adults with ASD was demonstrated by significantly negative correlations of the Metacognition Index and TL-D performance. This index scale reflects the individual's ability to initiate activity and generate problem-solving ideas, to sustain working memory, to plan and organize problem-solving approaches and to organize one's materials and environment. Thus, metacognitive EF difficulties in daily life in individuals with ASD are associated with worse TL-D performance.

We explored processing speed in relation to EF tasks in older adults with ASD. Individuals with ASD performed on an average level and similar to TD controls on a processing speed measure (PSI tasks of the WAIS-IV), consisting of two time restrained complex attention tests. However, individuals with ASD did need more time than TD controls to execute the complex EF task (TL-D) for a similar or even better performance. This was unrelated to the complexity of this EF task; we observed a similar complexity-effect in individuals with ASD and TD controls with more complex EF tasks requiring more execution time. Furthermore, in individuals with ASD processing speed on a complex attention test was not associated with execution times of EF tasks, and not with EF performance. Only in TD controls, processing speed on a complex attention test was positively associated with performance on both fluency tasks. This study therefore provides no support for a generally reduced processing speed in older adults with ASD, but points to a generally reduced processing speed during complex tasks of EF. This could be interpreted as a strategic compensation for the EF difficulties

experienced, although more research is needed. Investigating the time necessary to complete complex tasks could move the field further in terms of an EF model for older adults with ASD. In order to develop such model it is important that more studies on the effect of ageing in ASD are conducted. Our study found similar associations between age and semantic fluency (a measure of producing new responses, and adequate search strategies and flexibility in thinking) in older adults with and without ASD, with reduced performance with increasing age. Future studies should address the question how aging affects individuals with ASD differently.

As mentioned in the introduction, processes of development and decline of EF are heterogeneous over the life span (Jurado and Rosselli 2007). The severity of EF deficits in ASD may vary per domain and across life phases (Hill 2004, Happé et al. 2006, Van den Bergh et al. 2014). Studies examining EF in samples of different ages, including adult patients, suggested that EF problems wane with age (Geurts and Vissers 2012; Happé and Charlton 2012). It has been assumed that, towards adulthood, persons with ASD could catch up with cognitive development, learn to use effective compensation strategies or even profit from cognitive reserve protecting them from cognitive aging. According to these studies, this could be attributed to the atypical brain development in ASD.

Strengths and Weaknesses

Strengths of this study were the rigorous face-to-face assessments and the use of a test battery measuring objective performance as well as subjective complaints. The combination of objective and subjective measures provides distinct and unique types of information that are relevant for clinical practice with regard to identifying and differentiating subjective complaints of relatives and the patients' awareness of their own executive (dys)functioning. Furthermore, in order to exclude confounders, the ASD and control group were well matched for age, education level and gender. With regard to gender, males outnumbered females (30:6) and this limits the generalisation of the present results to males rather than females with ASD.

Even though older adults with ASD had more subjective complaints about EFs in real life, an important limitation of this study is that the relationship between EFs and quality of life and independent living was not investigated. In a meta-analysis on the quality of life (QoL) across the lifespan in persons with ASD a lower QoL was found compared to persons without ASD, regardless of age (Van Heijst and Geurts 2014).

Recent studies predicted that real-world EF problems on metacognition in children with ASD were indicative of

impaired adaptive functioning later in life (Pugliese et al. 2015). In adulthood these real-world EF problems were associated with impaired adaptive functioning (Wallace et al. 2016). Future studies should therefore relate neuropsychological deficits and complaints to adaptive functioning in real life.

A limitation regarding the design of this study is that the order of the neuropsychological tasks was not counter balanced between participants, and therefore a fatigue effect could be present for the EF tasks because these were placed after the intelligence assessment. However, as all participants received the tasks in the same order, we assume this effect to be equal for all participants. Another limitation was the use of short versions of the semantic and phonetic fluency tasks in order to reduce the length of the test battery. The different results between our study and previous studies (e.g. Geurts and Vissers 2012) on the phonetic fluency task could be explained by a higher task demand on the standard phonetic fluency task (three times 1 min per letter) compared to our short version (one time 1 min per letter).

All of the individuals in our ASD group had received an ASD diagnosis in late adulthood (after age 30) and had likely reached a threshold of suspicion late due to less severe symptoms and/or impairments, better coping and/or compensation skills, or protective environmental factors. Because participants were all first diagnosed later in life the EF problems they report might be an underestimation of the EF problems in the total adult population with ASD. This group bias could also account for the relatively low percentage of the individuals with ASD reporting severe problems with social responsiveness (SRS-A). However, 50 % of the group still reported mild to moderate difficulties in every day social interaction, indicating deficiencies in reciprocal social behaviour which are typical for individuals with mild or "high functioning" autism spectrum disorders.

Besides this group bias, another important limitation of this study is that individuals with ASD from a specialized ASD outpatient clinic population. These individuals with ASD came in for treatment and may have had more (comorbid) complaints than individuals with ASD not in treatment, possibly giving rise to selection bias. We found that the patients using antidepressants or stimulants report both more complaints with EF and also more severe autism symptoms. This could either be due to a medication effect or an effect of the (comorbid) psychiatric condition for which the medication was prescribed (Durak et al. 2014; Porter et al. 2003; Snyder 2013). Although our study sample consisted of a relatively small number of participants, the number of individuals with ASD with a rigorously assessed and validated ASD-diagnosis may be considered substantial. In addition, due to the cross-

sectional design of our study, current findings do not elucidate the process of aging in ASD and because some EF do not start declining until the age of 70 in typically functioning adults (Andrés and Van der Linden 2000; Jurado and Rosselli 2007), a larger group of 70+ people (with and without ASD) should be included in future longitudinal research. Although the BRIEF-A questionnaire assesses EF it does not take into account the time needed to perform tasks or solve problems into account.

Conclusions and Clinical Recommendations

Our main finding is that older persons with ASD need more time to execute EF tasks in order to achieve the same (or even better) results than TD controls, and that they report more EF problems in daily living. Everyday life is infinitely more complex with more time pressure than even the most difficult EF tasks used in clinical neuropsychological assessment. We speculate that older individuals with ASD report many EF difficulties in daily living due to the time constraints of everyday tasks, and that reducing time pressure could help them overcome their difficulties with complex tasks. Most neuropsychological outcome measures used in this study seem to lack sensitivity to demonstrate EF problems in individuals with ASD, except for the time to execute a complex planning task. More attention to the process of task execution could provide insight into factors underlying EF performance of older adults with ASD in daily living. For example: execution time in EF tasks could be measured at different time points during the task. In ToL and Zoo maps, the time for planning and execution could not strictly be separated, because planning was still continuing during the execution of the task. Tasks that strictly separate planning and execution could provide more insight onto the factors that delay task execution and compensation strategies that are used by individuals with ASD.

Problems with EF tasks are not specific for ASD, but are also seen in other developmental (e.g. ADHD), neurological (e.g. dementia, Parkinson's disease) and psychiatric (e.g. depression) disorders and therefore cannot be used to diagnose ASD (Geurts et al. 2004; Koerts et al. 2012; Martínez-Arán et al. 2004; Pennington and Ozonoff 1996). Our results did not change when participants using medication for comorbidities were excluded, which demonstrates a specific relatedness between execution time of EF tasks and complaints about EF-difficulties in real life and having ASD. Healthy ageing studies found that executive dysfunction is a key contributor to impairment in activities of daily living while processing speed has been identified as an important predictor of independence in daily functioning (Bell-McGinty et al. 2002; Gothe et al. 2014; Jurado and Rosselli 2007; Marshall et al. 2011).

EF problems have a large impact on daily functioning, and assessment of EFs is important to inform treatment interventions. Of the included objective and subjective EF measures in our study, the ToL (TL-D) and the BRIEF-A appeared to be the most useful measures for predicting EF difficulties in clinical practice. In addition to accuracy, execution times are also valuable variables to take into account when assessing objective EF performance. Based on perceived differences in EF between individuals with ASD in this study and young persons with ASD in earlier studies, we hesitate to conclude that EF deficits in ASD wane with age or that these differences in EF are biased by group differences. A perceived improved performance on for example planning and set-shifting task in the second part of childhood in ASD (Luna et al. 2007; Pellicano 2010a, b) was clearly found not to lead to the same level of achievement of typically developing individuals, which is consistent with the results of individuals with ASD participating in our study. Longitudinal studies are necessary to detect and conclude whether cognitive changes occur with progressing age in ASD.

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Author Contributions RD conceived of the study, participated in its design and coordination, performed the measurement, performed the statistical analysis and the interpretation of the data and drafted the manuscript; YG participated in its design and the coordination, helped with the acquisition, the statistical analysis and the interpretation of the data and helped to draft the manuscript; IJB participated in the design and interpretation of the data and revised the manuscript critically; OT participated in the design and revised the manuscript critically; IDCvB participated in its design, the interpretation of data, revised the manuscript critically and helped to draft the manuscript. All authors read and approved the final manuscript.

Compliance with Ethical Standards

Conflict of Interest Roeliena C. D. Davids, Yvonne Groen, Ina J. Berg, Oliver M. Tucha and Ingrid D. C. van Balkom declares that she has no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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