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ORIGINAL PAPER

Heterogeneity of Strengths and Challenges in Executive Functions of Autistic Children and Adolescents

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Abstract

Objectives Individuals with autism often experience difficulties with executive functions (EF). Some of these EF are, in turn, associated with certain behavioural autism characteristics. This study explored the intra- and inter-individual variability between autistic children in each of the EF components. Furthermore, this study aimed to delineate subgroups of autistic children and adolescents with different EF profiles and examined whether these subgroups are distinguished by differences in autism characteristics.

Methods A sample comprised 58 autistic individuals and 47 non-autistic controls, aged between 8 and 18 years. Eight lab-based EF tasks were administered to measure EF domains: working memory, inhibition, cognitive flexibility, generativity, and planning. Additionally, a parent-reported daily-life EF measure was used to assess how these abilities manifest in real-life contexts.

Results A multiple case series analysis revealed that most autistic individuals performed similarly to the non-autism group on all lab-based EF tasks, and no autistic participant experienced difficulty with all EF measures. However, most individuals seemed to face a particular challenge in daily-life EF, as reported by parents. Furthermore, a cluster analysis was performed to delineate more homogenous subgroups with similar EF profiles within the autistic group. Three subgroups were identified and characterised by (1) challenges with internally controlled cognitive flexibility and planning, (2) challenges with internally and externally controlled cognitive flexibility and (3) no EF-related difficulties. These clusters did not differ in terms of social communication and interaction; however, they significantly differed regarding restricted, repetitive patterns of behaviour and interests.

Conclusions Distinct subgroups within the autistic group with unique EF profiles (weaknesses and strengths) were identified providing insight into the specific patterns of difficulty crucial for tailor-made interventions.

Keywords Executive function · Strength · Weakness · Autism · Children · Adolescents

Individuals with autism often experience difficulties with executive functions (EF), which are, in turn, associated with certain behavioural autism characteristics. In this study, the term "autism" is used to acknowledge diverse views on the condition, unless specifically referring to an autism spectrum disorder (ASD) diagnosis based on the Diagnostic and

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Statistical Manual of Mental Disorders (DSM-5; American Psychiatric Association, 2013) criteria. A combination of identity-first (e.g. autistic child) and person-first (e.g. child with autism) language is employed, as preferences vary within and between English-speaking and Dutch-speaking communities (e.g. Bottema-Beutel et al., 2021; Buijsman et al., 2022). To elucidate inconsistencies in current research findings, often resulting from variability in sample and task characteristics, this study explores the heterogeneity in EF between and within autistic individuals. Specifically, it (1) focuses on the intra- and inter-individual variability between autistic children in each of the EF components, (2) aims to delineate autism subgroups with different EF profiles and (3) examines whether these subgroups are characterised by differences in autism characteristics.

Generally, ASD is described by atypicalities in social communication and interactions, as well as by restricted, repetitive patterns of behaviour and interests (RRBIs), according to the DSM-5-TR (American Psychiatric Association, 2022). Research suggests that autistic individuals, when compared to their typically developing peers, experience challenges in the EF domains (Demetriou et al., 2018; St John et al., 2021; Pellicano et al., 2017). Despite various definitions, generally, EF is referred to as a set of interrelated but distinct functions necessary for carrying out higher-order cognitive processes (Goldstein et al., 2014). As defined by Pennington and Ozonoff (1996) and Hill (2004), the EF domains are as follows: (1) working memory — ability to hold certain information in mind while performing a task; (2) inhibition — ability to control impulses and suppress certain behaviour or to ignore distracting information; (3) cognitive flexibility (or set-shifting) — ability to shift between different thoughts or actions following changes in a situation; (4) generativity (or fluency) — ability to generate novel ideas; and (5) planning — ability to look ahead before starting to perform a task. Numerous studies support the existence of diverse EF profiles in typically developing children and in children with both acquired and developmental disorders (Martarelli et al., 2018; Shakehnia et al., 2021). Although not exclusive to individuals with autism, it is generally accepted that they experience particular EF difficulties (see meta-analysis by Demetriou et al., 2018), with the most prominent ones occurring in cognitive flexibility (see a review by Leung & Zakzanis, 2014), verbal and spatial working memory (see meta-analysis by Wang et al., 2017) and planning (van den Bergh et al., 2014) domains. However, most studies, supporting such EF challenges, employ the deficit-based framework, resulting in a limited focus on EF strengths in autistic individuals (Bottema-Beutel et al., 2021). Nevertheless, some researchers shifted their attention to the strengths-based approach and have identified EF strengths across a range of subdomains and tasks (Abbott et al., 2018; St John et al., 2021). To interpret the inconsistencies in the findings, important influential factors should be considered.

Firstly, reported performance variability might be attributed to sample characteristics. Appropriate group matching criteria are crucial in studies using group comparisons. Participants may differ in aspects, such as their clinical status, age (or maturation) and intelligence (IQ), which might influence their EF abilities (Craig et al., 2016; Mous et al., 2017). Therefore, it is important that matching criteria align with the aim of the study and particular research question, and reported strengths and weaknesses in EF (and its domains) in those with autism are interpreted accordingly. Nevertheless, such group comparisons can already be biased. If a significant group difference is found between the autism and the control group, it is often concluded that weaknesses in EF are present in all autistic individuals. However, not all cognitive characteristics (limitations in one or more of the EF domains) are evident in every autistic individual, and they tend to vary in severity (Brunsdon et al., 2015). This variance can be attributed to the diversity of individuals within the autism group, whether in language abilities (Weismer et al., 2018), the severity of behavioural characteristics (Mostert-Kerckhoffs et al., 2015) or the presence of a co-occurring disorder (for a review see Craig et al., 2016). Recognising individual differences is important when exploring EF difficulties in those with autism (Vries and Geurts, 2015; Leung & Zakzanis, 2014; van den Bergh et al., 2014). Some studies have investigated inter-individual variability in EF to identify heterogeneous EF profiles (Cordova et al., 2020; Feczko et al., 2017; Gonzalez-Gadea et al., 2013) and reveal individual strengths not demonstrated in group analyses (Demetriou, Demayo, & Guastella, 2019; Tschida & Yerys, 2021). Given the inter-individual variability in EF in autistic youth, analysing individual performance is needed for detecting weaknesses, strengths and unique patterns of difficulty (Feczko et al., 2017; Gonzalez-Gadea et al., 2013) crucial for tailor-made interventions (Leung et al., 2016).

Secondly, reported performance variability might be attributed to task characteristics. Various tasks are proposed to measure domain-specific EF or a broad concept of EF ability; however, the format of each measurement could contribute to inconsistent findings across the literature. Research suggests that autistic individuals tend to face more challenges in open-ended tasks compared to highly structured tasks (Patros et al., 2019; White et al., 2009). Van Eylen and colleagues (2015) suggested that open-ended tasks might demand and require more executive control, therefore making them more sensitive to EF difficulties, while highly structured tasks relieve some demands placed on EF. Some studies propose that socio-communicative difficulties (no explicit instructions are provided, instead the information has to be inferred implicitly) can put individuals with autism at a disadvantage in open-ended test situations (White et al., 2009). Previously, it was reported that autistic individuals perform as well as controls on EF tasks presented in a computerised

format versus traditional presentation of test material, most likely due to a poor understanding of the instructions presented by the experimenter (Williams & Jarrold, 2013). However, such lab-based highly controlled EF measures might not be fully representative of executive functioning in 'real-life' contexts. Recent studies have supplemented lab-based tasks with behavioural rating scales (e.g. the Behaviour Rating Inventory of Executive Function (BRIEF); Gioia et al., 2000), aiming to provide a more ecologically valid assessment of EF abilities in daily life (Barkley, 2015). These real-life assessments, based on parent (or teacher) reports, often reveal that autistic individuals face challenges in daily-life EF, even when their performance on highly structured laboratory tasks appears satisfactory (Blijd-Hoogewys et al., 2014). This contrast suggests a potential disconnect between lab-based and real-world EF performance, underscoring the importance of including daily-life EF measures like the BRIEF to provide a more comprehensive view of EF difficulties in autism. Therefore, the choice of EF measurement — whether lab-based or real-life — might overemphasise or understate reported difficulties in those with autism. The inclusion of both types of assessments allows for the investigation of potential discrepancies between these environments. Inconsistent results may also be attributed to so-called task impurity (Van Eylen et al., 2015). Numerous methods of measurement have been introduced and claim to measure (the distinct components of) EF; however, given the complexity of and overlap between these constructs, the validity and reliability of each measure ought to be assessed.

Current Study

Given the heterogeneity of autistic individuals, this study will investigate the inter-individual variability in EF in the autism sample and will explore whether distinct autism subgroups could be delineated, each with a distinct EF profile, and will further examine whether these differences in EF profiles correspond to the variability in autism characteristics.

Concerning the heterogeneity of the EF construct, this study will explore the intra-individual variability across all EF measures. Each EF domain will be measured separately to identify localised difficulties by choosing one instrument assessing the underlying EF ability. These instruments will be selected based on Van Eylen and colleagues (2015) findings, specifically those with the strongest effect for each particular EF ability. Taking into account the above-mentioned task characteristics, this study will employ a combination of open-ended and more structured measures to provide insight into the performance of autistic individuals in a controlled laboratory setting, as well as in daily life.

Therefore, this study will assess a range of EF processes allowing for the investigation of the influence of task and sample characteristics independently and providing a broad picture of the EF profile in autism. As such, the research aims are as follows: (1) to chart the heterogeneity of EF within autism, (2) to delineate more homogeneous subgroups based on EF and (3) to examine whether these distinct subgroups are marked by differences in autism characteristics.

Methods

Participants

The data from a previous study on group differences in EF between autistic children/adolescents and non-autistic controls was re-analysed Van Eylen and colleagues (2015). The original study included 116 Dutch-speaking participants, aged between 8 and 18 years, with a verbal (VIQ), performance (PIQ) and full-scale IQ (FSIQ) above 70, as well as normal or corrected-to-normal vision (wearing glasses or lenses) without colour-blindness.

The first subgroup comprised 58 autistic participants recruited through the Leuven Autism Research (LAuRes) database. The formal diagnosis of ASD was made by a multidisciplinary team according to the DSM-IV-TR criteria (American Psychiatric Association, 2000). The diagnosis was confirmed by the Developmental, Dimensional and Diagnostic Interview (3di; Skuse et al., 2004) for all autistic participants, except five. Fifteen individuals were diagnosed with one or two co-occurring disorder(s): seven — attention deficit hyperactivity disorder (ADHD); five — dyslexia; two — developmental coordination disorder; two — anxiety disorder; one — depression; and one — tic disorder. Additionally, six individuals took psychoactive medication during the study. To portray the full spectrum and thus map the heterogeneity across the autism group, individuals without a confirmed 3di ASD diagnosis, as well as those with a co-occurring disorder, were included. To investigate whether analyses would yield a different pattern of findings, some analyses were performed with the 'restricted' autism sample, excluding participants without a 3di-validated ASD diagnosis.

The second subgroup included 58 non-autistic children recruited through various channels, including but not limited to schools, personal contacts and advertisements. Based on the autistic individuals that enrolled in the study, the participants in the control group were matched by age and gender to the recruited autistic participants. Additionally, all participants were required to have an IQ score falling within the normal range. The groups were further matched based on their PIQ, reflecting the performance-based nature of the tasks used in the

study. Regarding the control group, neither participants nor any of their first-degree relatives had a neurological or psychiatric disorder, according to the parental reports. The Social Responsiveness Scale (SRS-2; Constantino & Gruber, 2012) was administered to all participants in this subgroup to assess autism characteristics. Based on this assessment, 11 participants were excluded from the data analysis: three children showed elevated autism characteristics, scoring two standard deviations (SDs) above the mean on the SRS-2, while the SRS-2 total score of eight participants could not be calculated due to missing values, therefore resulting in exclusion.

The analyses were performed on a sample comprising 105 participants: 58 autistic individuals and 47 controls. Descriptive statistics are displayed in Table 1.

Procedures

Participants were tested individually in a quiet room, either at the University Hospital or at school. The testing procedure (including additional visual processing tasks administered as part of another study) took four one-hour sessions. Enough breaks were provided to avoid fatigue; when the participant became inattentive, the task was paused and only resumed once the participant was ready to proceed. The order of sessions and tasks within the session were counterbalanced to avoid order effects. Informed consent was obtained from the participants' parents and the participants themselves if they were 16 years and older. The study protocol was approved by the Medical Ethical Committee of the University Hospitals Leuven and the Social and Societal Ethics Committee (SMEC) of KU Leuven. For a description of the data collection procedure, see Van Eylen and colleagues (2015).

Intelligence

Intelligence was assessed using an abbreviated version of the Dutch Wechsler Intelligence Scale for Children (WISC-III-NL; Kort et al., 2005) or Wechsler Adult Intelligence Scale (WAIS-III-NL; Wechsler, 2005), including Vocabulary, Similarities, Picture Completion, and Block Design subtests (Sattler & Saklofske, 2001).

Inhibition

A computerised Go/No-Go Task (described by Christ et al., 2007) measured response inhibition. The participants were asked to press a response button as fast as possible when a circle or a square was shown on the screen (Go-trial). No response was to be given when a triangle appeared on a screen instead (No-Go-trial).

Participants completed 120 randomly intermingled trials comprising 20 percent of No-Go trials. The outcome measure was the percentage of wrong answers on No-Go trials (No-Go errors).

The Flanker Task (described by Christ et al., 2011) measured resistance to distractor interference. The participants had to press the left or right response button corresponding to the central arrow displayed on the screen. In the compatible trials, the middle arrow was surrounded by two arrows on each side pointing in the same direction, while, in the incompatible trials, the surrounding arrows pointed in the opposite direction than the target arrow. Participants completed 120 (60 compatible and 60 incompatible) randomly intermingled trials. The outcome measure (inhibition cost) was the mean response time and the error percentage on incompatible minus compatible trials.

Cognitive Flexibility

The Wisconsin Card Sorting Task with Controlled Task Switching (WCST-WCTS; described in Van Eylen and colleagues, 2011) required internally controlled rule shifting.

Table 1 Demographic information of autistic participants and non-autistic controls

Characteristics	**Autism group** ($n=58$) Mean (SD)	**Non-autism group** ($n=47$) Mean (SD)	**Test statistic** (df)	***p***
Sex: *n* (%)			$\chi^2(1)=0.717$	0.397
Male	38 (65.52%)	27 (57.45%)		
Female	20 (34.48%)	20 (42.55%)		
Age in years	12.54 (2.47)	12.87 (2.87)	$t(103)=-0.631$	0.529
VIQ	102.78 (17.21)	114.23 (13.46)	$t(103)=-3.732$	<0.001
PIQ	102.45 (13.98)	106.81 (13.84)	$t(103)=-1.597$	0.113
FSIQ	102.61 (12.44)	110.52 (10.93)	$t(103)=-3.417$	0.001

SD standard deviation, *df* degrees of freedom, *VIQ* verbal IQ, *PIQ* performance IQ, *FSIQ* full-scale IQ

Three cards were displayed on the computer screen: one at the top and two at the bottom. Participants were asked to match one of the bottom cards to the top card, based on either colour or shape. The correct sorting rule was not made explicit but had to be derived based on the feedback provided; the rule changed without warning after several consecutive trials. The outcome measure was the mean number of perseveration errors (difficulty in shifting to a new sorting rule).

The Switch task (based on Rubia et al., 2007) assessed externally controlled rule shifting. Participants were shown a grid divided into four squares with a double-headed arrow pointing either horizontally or vertically. This was followed by a red dot displayed in one of the squares. If the arrow pointed horizontally, participants had to indicate whether the dot was on the left or right side of the grid; if the arrow pointed vertically, participants had to indicate whether the target was in the lower or upper half of the grid by pressing a button on a diamond-like four-button response box. The task comprised four blocks, each containing 36 trials. The outcome measure was the switch cost error percentage (switch trial error % minus maintain trial error %).

Working Memory

The Spatial Working Memory Test is part of the Cambridge Neuropsychological Test Automated Battery (CANTAB; Fray & Robbins, 1996), assessing the ability to retain and manipulate spatial information. The participant was presented with some boxes on a touch screen and was asked to find a 'token' in one of the boxes; note that the token was never hidden in the same box within the same trial; the test comprised 12 trials. An error was defined as the selection of the box that was previously found to be empty (either in the previous or current search). The outcome measure was the number of errors.

The Spatial Span subtest of the Wechsler Non-Verbal-NL (Wechsler & Naglieri, 2006) measured spatial working memory. The participant was presented with a board containing 10 blocks in a specific configuration. The experimenter then tapped a number of blocks and the participant had to touch the same blocks, either in the same order (forward condition) or in the reversed order (backward condition). Each condition consisted of 16 experimental trials (sequentially increasing the number of tapped blocks from two to nine, with two trials for each number). The outcome measure was a total of correct trials (combined number of correct trials for the forward and backward conditions).

Generativity

The Uses of Objects task (Bishop & Norbury, 2005; Turner, 1999) measured the ability to generate new ideas (ideational fluency). Participants were asked to generate as many useful uses as they could for six different objects (90 seconds per object), half being conventional items (obvious function) and half non-conventional (no clear function) items. The outcome measure was the total number of correct responses (for the conventional and non-conventional items combined).

The Design Fluency test is part of the Delis-Kaplan Executive Function System (D-KEFS; Delis et al., 2001; Dutch adaptation by Noens & van Berckelaer-Onnes, 2007a) measuring more constrained generativity. In this task, rows of boxes were presented on a piece of paper, with each box containing the same array of black dots. The participant was asked to draw a different design in each box by connecting the dots using four straight connected lines. The number of unique and correct designs provided an outcome measure.

Planning

The Tower test of the D-KEFS (Delis et al., 2001; Noens & van Berckelaer-Onnes, 2007b) assessed planning. Participants had to build a designated tower in as few moves as possible by moving five disks varying in size across three pegs; the test consisted of nine items. The move accuracy ratio (the actual number of moves performed divided by the number of minimally required moves) reflected the effectiveness of the employed strategy and was used as an outcome measure.

Executive Function in Daily Life

The BRIEF (Smidts & Huizinga, 2010) questionnaire was administered to the parents to assess EF difficulties in daily life (referring to the last 6 months). The outcome measure was the total score, comprising inhibition, shifting (flexibility), working memory and planning.

Autism Characteristics

The SRS-2 (Constantino & Gruber, 2012) assesses a wide range of behaviour characteristics of autism, consisting of five 'treatment scales': social awareness, social cognition, social communication, social motivation and autistic mannerisms. The outcome measure of social communication and interaction symptoms (consistent with DSM-5; APA, 2013) was obtained by summing the scores of the four 'social' scales.

The Repetitive Behaviour Scale-Revised (RBS-R; Bodfish et al., 2000) assesses the RRBIs observed in autistic individuals. The total score of the scale was used as the outcome measure. The questionnaire was translated to Dutch by translation and back-translation.

Table 2 Administered instruments and selected outcome measures

EF domain	Instrument	Characteristic	Outcome measure
Inhibition			
• Response inhibition	Go/No-Go Task	Lab-based	No-go errors %
• Distractor interference	Flanker Test	Lab-based	Inhibition cost RT (ms)
Cognitive flexibility			
• Internally controlled	WCST-WCTS	More open-ended/lab-based More	Perseveration errors
• Externally controlled	Modified Switch Task	structured/lab-based	Switch cost error %
Working memory	Spatial Working Memory Test (CANTAB)	More open-ended / lab-based	Box selection errors
	Spatial Span Subtest (Wechsler Non-Verbal-NL)	More structured / lab-based	Correct trials
Generativity			
• Ideational fluency	Uses of Object Task	More open-ended/lab-based More	Correct responses Cor-
• Design fluency	Design Fluency Test (D-KEFS)	structured/lab-based	rect responses
Planning	Tower of California (D-KEFS)	Lab-based	Move accuracy ratio
Daily life	BRIEF questionnaire	Most open-ended/'real-life'	Total score

WCST-WCTS Wisconsin Card Sorting Task-With Controlled Task Switching, *CANTAB* Cambridge Neuropsychological Test Automated Battery, *D-KEFS* Delis-Kaplan Executive Functions System, *BRIEF* Behaviour Rating Inventory of Executive

Measures

A selection of measures used in the previous study was selected Van Eylen and colleagues (2015). Nine EF tasks were administered to measure five EF domains; for each EF task, one outcome measure was selected. If group differences on a task were previously found, the outcome measure with the largest effect size was chosen to explore the inter-individual variability between autistic participants on measures where the autism group showed challenges. Otherwise, the most normally distributed measure was selected, thereby excluding variables showing floor or ceiling effects within the non-autism group. Furthermore, the total score on the BRIEF (Smidts & Huizinga, 2010) was used to assess daily-life EF. For detailed descriptions of the measures administered, see Van Eylen and colleagues (2015). The selected outcome measures per domain are presented in Table 2, which can be found at the end of the section after all the instruments have been introduced.

Data Analyses

Multiple Case Series Analysis (MCSA)

MCSA was performed to map the heterogeneity of EF performances within the autism and non-autism groups. Additionally, the inter- and intra-individual variability in EF measures was investigated. For each of the outcome measures and each participant with autism, z-scores were calculated to inform on how many SDs the observed value of the autistic participant deviated from the expected value for a non-autistic individual; specifically, the mean, age-corrected, score of that of the non-autism group.

These z-scores were calculated by taking subsequent steps. Prior to the analysis, appropriate transformations were applied to obtain normally distributed outcome measures for the non-autism group. Square root transformation was applied to the Go/No-Go task, Flanker test, Uses of Objects and Design Fluency tasks.

Logarithm base 10 transformation was applied to the WCST-WCTS task and the BRIEF questionnaire. Following this, given the large influence of age on most EF measures, the age effect was controlled for (see a review by Schirmbeck et al., 2020). For each outcome measure of the EF tasks, a regression analysis was performed on the data of the non-autism group with age as the independent variable and by calculating the residuals. The effect of age squared was also added to the model (to investigate non-linear developmental patterns) when it significantly contributed to the prediction of the dependent variable above the effect of age. This resulting model was used to calculate residuals for each autistic participant on each of the outcome measures. Specifically, the predicted value for a non-autistic participant was computed and the difference between this predicted value and the observed value of the autistic participant of the same age was calculated. The same procedure was applied for the outcome measures of the questionnaires, except when the questionnaires were normed. In the latter case (for the BRIEF and SRS-2), age- and gender-corrected t-scores were calculated. Finally, the age-corrected scores (the residuals or t-scores) were used to compute z-scores by calculating the difference between the age-corrected score of the participant with autism and the mean age-corrected score of the non-autism group (the mean of the residuals of the non-autism group, which is always zero) and by dividing

this difference by the SD of the age-corrected score of the non-autism group.

For some of the measures (the Design Fluency task, the Uses of Objects task and the Spatial Span task), the z-scores were transformed (multiplied by -1), so that positive z values indicate worse performance compared to the mean, age-corrected, score of the non-autism group.

Per EF measure, the percentage of autistic participants who performed atypically (better- or worse-than-expected) compared to the non-autism group was then calculated.

The same cut-off as Geurts and colleagues (2014) was applied to determine better-than-expected performance (a score below the 10th percentile of the non-autism group, thus corresponding to a z-score below -1.28). A worse-than-expected performance corresponded to a score higher than the 90th percentile of the non- autism group (the z-score was higher than 1.28). The average performance was defined by the score between the 10th and 90th percentile of the non-autism group (the z-score between -1.28 and 1.28).

Cluster Analysis

A cluster analysis was performed to delineate more homogenous subgroups (based on the differences in EF performance) with a more similar EF profile within the autism group. K-means cluster analysis was performed on the normed z-scores (described in the section above) for all EF domains. For each EF domain, one measure (that with the highest variance within the autism group) was selected to weigh all domains equally in the analyses.

K-means cluster analysis divides n objects into K homogeneous clusters (where $K < n$). This analysis aims to minimise the variance within each cluster while maximising the variance between the clusters. The cluster analysis was run with the number of clusters varying from 1 to 8. Per number of clusters, the algorithm was run 999 times, each time starting from a different random start. Next, a scree test (Wilderjans et al., 2013) was used to determine the optimal value of K, that is, the number of clusters that optimally balances within-cluster variance and complexity.

To determine better- or worse-than-expected performance for each of the clusters, the mean normed z-score of each cluster was compared with the cut-off used in the MCSA (a z-score greater than 1.28 indicates a better performance, while a z-score below -1.28 indicates a worse-than-expected performance).

Afterwards, a one-way analysis of variance (ANOVA) was performed to investigate the differences between the clusters regarding the EF domains and the autism characteristics (SCI measured by the SRS-2 and RRBIs — by the RBS-R). Whenever significant differences were found, a post hoc contrast was calculated by using Tukey–Kramer correction to examine which specific clusters differed significantly from each other.

Finally, χ^2 tests were used to evaluate whether the participants with a 3di confirmed ASD diagnosis or another co-occurring disorder differed between the clusters. In order to check whether the clusters varied in the degree to which the SRS-2 score of these participants differed from that of non-autistic controls, these analyses were performed on the z-scores based on the comparison with the non-autism sample.

Results

MCSA: Inter- and Intra-variability in EF Within Autism

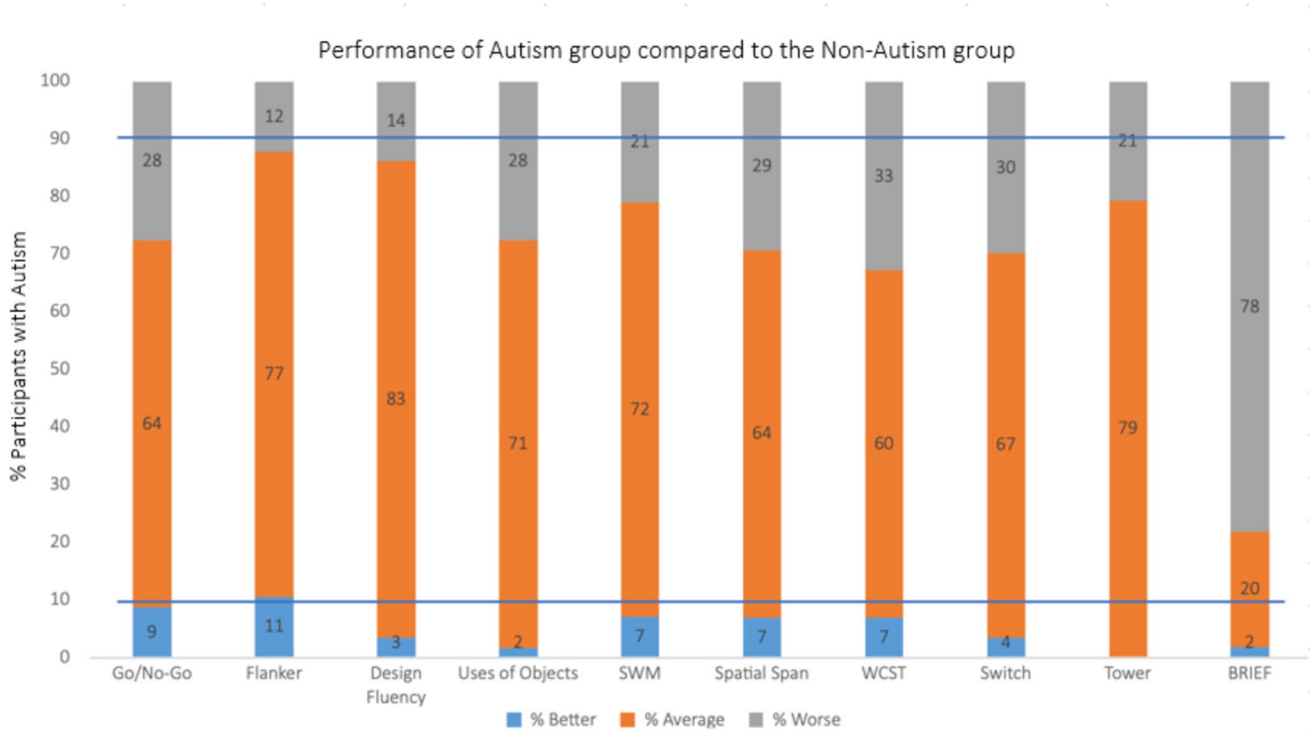
By using MCSA, the percentage of autistic individuals who performed worse-than-expected, average, or better-than-expected compared to the non-autistic controls was calculated. For most of the EF tasks (excluding the BRIEF questionnaire), at most 33% of the autistic individuals performed worse than expected. Most individuals with autism performed similarly to the non-autism group on all tasks, with a small percentage of the autism group performing better than expected, except on the planning subdomain (the Tower task). Notably, 78% of the autism group performed worse in daily-life EF (the BRIEF), while 20% showed average performance, and only 2% performed better than expected when compared to the control group. These results are summarised in Fig. 1.

Importantly, some autistic individuals (7%) demonstrated no difficulties with any of the EF measures. This percentage increased to 21% when the BRIEF questionnaire was excluded. Furthermore, no autistic participants experienced difficulty with all EF measures, and only one individual faced challenges with 7 out of 10 measures. Sixty-two percent of the autistic participants did not outperform the non-autistic controls on any task (same percentage if in/excluding the BRIEF), and 38% performed average or better than the 90th percentile of the non-autism group on at least one EF measure, with 9 and 2% — on two and three EF measures, respectively. The data are illustrated in Fig. 2.

The results above are based on the comparison of the whole autism and the 'restricted' non-autistic sample.

Since the inclusion of individuals with ASD diagnosis not validated by the 3di could have led to the underestimation of the occurrence of EF difficulties, the analyses were re-run by comparing the 'restricted' autism sample with the 'restricted' non-autistic sample. Additional analyses yielded similar results revealing no differences between the samples.

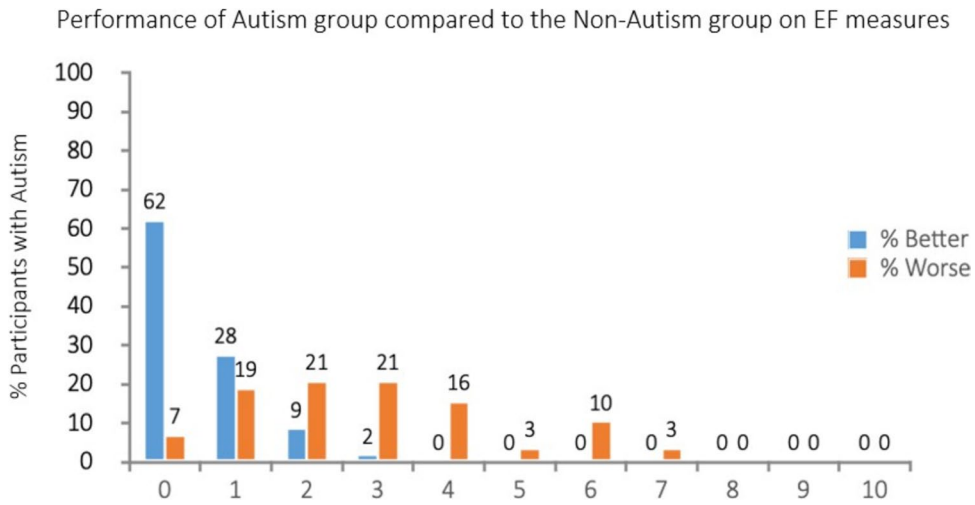
Finally, the mean, SD, minimum, maximum and range for each task were calculated (see Table 3), providing a more



Note: The lines indicate the cut-off: top line - 90th percentile while the bottom line - 10th percentile. SWM – Spatial Working Memory Test; WCST – Wisconsin Card Sorting Task-With Controlled Task Switching; BRIEF – Behaviour Rating Inventory of Executive Function.

Fig. 1 Performance of autistic participants compared to the non-autism group on EF tasks

Fig. 2 Performance of autistic participants compared to the non-autism group on zero to ten EF measures



detailed picture of the inter-individual variability per task. Generally, the range per task in the autism group was larger when compared to the non-autism group (except the Uses of Objects task). Notably, a pronounced difference can be seen in the externally controlled rule shifting performance (Modified Switch task) with a range of 10.72, indicating substantial variation within the autism group in this subdomain.

Cluster Analysis

The scree test indicated that a three-cluster solution provided the best fit-complexity balance. The first cluster, comprising 14 participants (24%), on average, achieved higher z-scores (above 1.28) on the WCST-WCTS ($M = 1.79$; $SD = 1.23$) and on the Tower test ($M = 1.82$; $SD = 1.25$) than the control group, indicating poorer performance on internally

Table 3 The performance of autistic participants on EF measures compared to the non-autism group

EF measure	Mean (SD)	Minimum	Maximum	Range	
				Autism group	Non-autism group
Go/No-Go Task	0.46 (1.13)	−2.88	2.50	5.39	4.56
Flanker Test	0.05 (1.37)	−2.90	5.25	8.16	4.60
Design Fluency Test	0.35 (0.97)	−1.83	2.65	4.48	4.60
Uses of Objects Task	0.76 (0.96)	−1.33	2.98	4.31	4.83
Spatial Working Memory Test	0.48 (1.02)	−1.97	2.57	4.54	4.06
Spatial Span Subtest	0.62 (1.20)	−2.18	3.06	5.24	4.47
WCST-WCTS	0.72 (1.37)	−1.98	3.92	5.90	5.35
Modified Switch Task	0.94 (2.18)	−1.49	9.22	10.72	5.24
Tower of California	0.45 (1.24)	−1.15	4.46	5.61	4.82
BRIEF	1.94 (1.23)	−2.09	4.21	6.30	4.94

WCST-WCTS Wisconsin Card Sorting Task-With Controlled Task Switching, *BRIEF* Behaviour Rating Inventory of Executive Function

controlled cognitive flexibility (rule shifting) and planning. The second cluster, comprising 9 individuals (16%), on average, achieved higher z-scores (above 1.28) on the WCST-WCTS ($M = 1.67$; $SD = 1.14$) and on the Switch task ($M = 5.24$; $SD = 1.65$) than the non-autistic controls, indicating difficulties with both cognitive flexibility subdomains: internally and externally controlled rule shifting. The third cluster, containing 35 autistic participants (60%), performed average on all of the EF tasks (z-scores between -1.28 and 1.28). Importantly, all clusters displayed a specific challenge with daily-life EF. This information is summarised in Fig. 3.

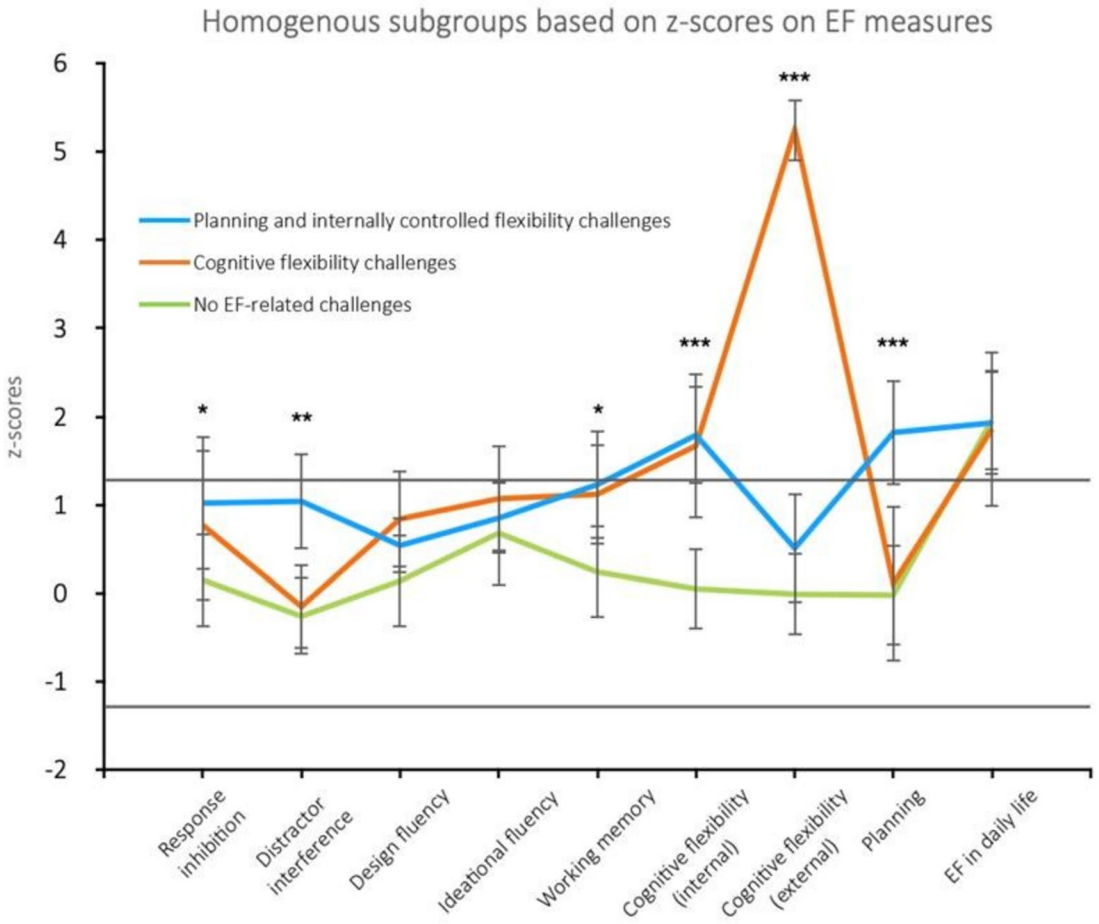
A significant difference was found in response inhibition between the clusters (see Table 4). Namely, cluster 1 scored significantly weaker on the Go/No-Go Task than did cluster 3 as indicated by the Tukey–Kramer correction, with similar patterns observed regarding distractor interference measured by the Flanker Test and Spatial Working Memory task. Significant differences were found in internally controlled rule shifting between the clusters; namely, cluster 1, as well as cluster 2, performed significantly worse than cluster 3 on the WCST-WCTS task. For the externally controlled rule shifting, cluster 1, as well as cluster 3, performed significantly better than cluster 2 (Modified Switch task). A significant difference was observed in planning (Tower of California task); namely, cluster 1 performed significantly weaker than both cluster 2 and cluster 3.

Additional significant differences between the clusters were further explored. Since the FSIQ score did not differ between the clusters ($F(2,55) = 1.13$; $p = 0.33$), there was no need to control for this factor. There was no difference between the clusters regarding the percentage of individuals without a 3di confirmed ASD diagnosis (cluster 1, 7%; cluster 2, 0%; and cluster 3, 11%; $\chi^2 = 1.24$; $p = 0.54$). The chi-square test showed that having a 3di confirmed diagnosis did not determine cluster differentiation ($\chi^2 = 0.15$; $p = 0.538$). No difference was observed between the clusters regarding the individuals with either a co-occurring ADHD diagnosis (cluster 1, 7%; cluster 2, 22%; and cluster 3, 11%; $\chi^2 = 1.21$; $p = 0.55$) or a co-occurring disorder in general (cluster 1, 14%; cluster 2, 44%; and cluster 3, 28%; $\chi^2 = 2.60$; $p = 0.27$). Again, the chi-square test indicated that having a co-occurring disorder did not determine cluster assignment ($\chi^2 = 0.49$; $p = 0.437$). Finally, ANOVA showed no significant difference in terms of social communication and interaction (SRS-2). However, the clusters differed significantly in terms of RRBIs (RBS-R), with cluster 1 outperforming cluster 2 according to the contrast analysis. Table 4 illustrates this information.

Discussion

The present study assessed EF heterogeneity in children with autism. The variation between and within autistic individuals was investigated, identifying distinct subgroups with unique EF profiles. These subgroups were then contrasted concerning the differences in autism behavioural characteristics.

In line with the previous studies, the results indicate that a small percentage of autistic children did not perform worse than the typically developing controls on any EF measure. When only looking at the EF tasks (excluding the daily-life EF measure), that percentage rose to a fifth of the autism sample. Furthermore, most of the autistic children performed similarly to the control group on most EF tasks. The findings of this study, therefore, suggest that EF-related difficulties are not a universal characteristic of autistic individuals (Brunsdon et al., 2015; Geurts et al., 2014; Towgood et al., 2009; van den Bergh et al., 2014). On the other hand,



Note: The cut-off lines indicate > 1.28 - worse than non-autistic controls while < -1.28 - better than non-autistic controls.
*$p < .05$; **$p < .01$; ***$p < .001$.

Fig. 3 Homogenous subgroups based on z-scores on EF measures

Table 4 Comparison between the three clusters regarding EF subdomains and autism behavioural domains

	Cluster 1 ($n = 14$)	Cluster 2 ($n = 9$)	Cluster 3 ($n = 35$)	ANOVA		Tukey–Kramer		
	M (SD)	*M* (SD)	*M* (SD)	*F*-value (df)	*p*-value	1 vs 2	2 vs 3	1 vs 3
EF subdomains								
Response inhibition	1.02 (0.70)*	0.77 (1.16)	0.15 (1.17)*	3.71 (2,55)	0.031	0.856	0.276	0.036
Distractor interference	1.04 (1.51)**	−0.15 (1.71)	−0.26 (1.06)**	4.98 (2,54)	0.010	0.094	0.968	0.008
Design fluency	0.54 (1.09)	0.84 (0.95)	0.14 (0.88)	2.36 (2,55)	0.104	-	-	-
Ideational fluency	0.85 (0.63)	1.07 (1.10)	0.68 (1.04)	0.60 (2,55)	0.554	-	-	-
Spatial working memory	1.23 (0.82)*	1.12 (1.20)	0.24 (1.20)*	4.95 (2,55)	0.011	0.971	0.100	0.020
Internally controlled rule shifting	1.79 (1.23)***	1.67 (1.14)**	0.05 (1.05)***	16.31 (2,55)	< 0.001	0.962	0.001	< 0.001
Externally controlled rule shifting	0.51 (1.11)***	5.24 (1.65)**	−0.01 (0.93)***	81.24 (2,54)	< 0.001	< 0.001	0.009	0.308
Planning	1.82 (1.25)***	0.11 (0.71)***	−0.02 (0.93)***	17.90 (2,55)	< 0.001	< 0.001	0.931	< 0.001
BRIEF	1.93 (1.19)	1.86 (1.76)	1.96 (1.14)	0.02 (2,52)	0.977	-	-	-
Autism behavioural domains								
SCI	5.31 (2.52)	5.52 (1.91)	4.96 (1.81)	0.34 (2,55)	0.713	-	-	-
RRBI	4.28 (2.48)	7.11 (2.59)	5.16 (1.69)	3.70 (2,37)	0.034	0.026	0.119	0.473

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

the majority of the autistic children performed worse than typically developing controls on at least one EF measure. However, there was not a single EF measure in this study on which all autistic children performed poorly, and not a single autistic child performed below average on all EF measures. Importantly, the individual analyses also showed EF strengths in children with autism. For instance, almost a third of autistic children performed better than the control group in one EF domain, and some individuals performed better in two EF domains.

Additionally, this study revealed significant variability between autistic children. This study defined subgroups based on EF profiles in autistic participants, adding to the scarce literature on subtyping autism into cognitive profiles (Nader et al., 2015; Vanegas & Davidson, 2015). Three subgroups, or three EF profiles, were identified. The first subgroup was weaker in planning, cognitive flexibility subdomain — internally controlled flexibility, and daily-life EF when compared to the control group and the other two subgroups. This 'subgroup with planning and internally controlled flexibility challenges' corresponds somewhat to an EF profile that appeared in some of the earlier peer-reviewed studies (Brunsdon et al., 2015; Lopez et al., 2005; Sinzig et al., 2008). The second 'subgroup with pronounced challenges in cognitive flexibility' was weaker in both internally and externally controlled cognitive flexibility and daily-life EF compared to the typically developing children and the other subgroups. These two subgroups each had a different profile at the level of cognitive flexibility. Van Eylen and colleagues (2011) formulated the hypothesis that individuals with autism experience particular challenges with internally controlled flexibility. This hypothesis is in line with the subgroup with planning and internally controlled flexibility difficulties, but not the second subgroup. Van Eylen and colleagues (2015) also reported that autistic individuals experienced challenges with cognitive flexibility when explicit instructions were provided regarding when and how to make the 'switch' in the task. Finally, a third subgroup with 'no EF related challenges' was identified, characterised by scoring average on all EF tasks compared to the typically developing controls. The majority of the autistic children fell into this subgroup; however, this group did have pronounced difficulties in daily-life EF. While these different EF profiles provide valuable insights into potential subgroup distinctions among autistic individuals, it is important to acknowledge that the practical application of these profiles to real-life settings should be approached with caution. These findings suggest possible explanations for some of the inconsistencies observed in studies that only perform group comparative analyses, but further research is needed to validate these profiles in naturalistic settings. Moreover, the results of this study revealed no significant correlation between the subgroups and 3di confirmed diagnosis. Most children without a 3di confirmed diagnosis fell into the 'no EF related challenges' subgroup, while all children in the 'subgroup with pronounced challenges with cognitive flexibility' received a 3di diagnosis. No further correlation was found with IQ and no significant relation with having a co-occurring disorder. Lastly, the relation between the differences in EF profiles and autism behavioural characteristics was investigated. All three subgroups of children with autism obtained high scores on both autism-related characteristics. Furthermore, the differences in EF profiles to some extent corresponded to the differences in behavioural autism characteristics. More specifically, the subgroup with pronounced cognitive flexibility difficulties scored worst on the RBS-R measure, thus experiencing more pronounced RRBIs. This finding supported earlier literature, namely, a connection between cognitive flexibility and non-social autism characteristics (Brunsdon & Happé, 2014). No significant differences were found between the subgroups and social autism characteristics; previous research on this relation is rather inconsistent.

In addition, there was a lot of intra-personal variability, as some children performed worse on certain (sub)domains while performing better than the control group on other (sub)domains. These results were, once again, in agreement with previous studies (Geurts et al., 2014; Towgood et al., 2009) supporting the hypothesis that each autistic individual seems to present not only EF weaknesses but also particular EF strengths (Courchesne et al., 2015; Warren et al., 2021). However, the translation of these strengths and weaknesses into real-life contexts requires further investigation, as EF abilities measured in controlled settings may not fully capture the complexities of everyday functioning.

Regarding task characteristics, the difference in performance between open-ended and structured tasks was not clear. For instance, in terms of cognitive flexibility, a third of the autistic children performed worse than non-autistic controls on both open-ended (WCST-WCTS) and structured (Switch) tasks. These results are only somewhat in line with previous literature as majority of studies report more difficulties in the performance of autistic children when fewer instructions were provided (open-ended tasks) (Williams & Jarrold, 2013).

This study further reinforced the notion of the existence of subdomains within the main EF components.

More specifically, the results showed a significant difference in terms of the inhibition domain. The least number of children (only one-tenth) performed worse than their typically developing peers on distractor interference, while more than a quarter of autistic children performed worse on the response inhibition subdomain. Major differences in performance were also found between the subdomains of generativity. A small percentage of autistic children performed

worse on design fluency, while twice as many autistic children performed worse on ideational fluency. These results are in agreement with previous comparative studies, which note that autistic individuals tend to face difficulties with ideational fluency but not with design fluency (Kleinhans et al., 2005; Robinson et al., 2009; Van Eylen et al., 2017).

Additionally, this study administered a behavioural rating scale aiming to provide a more ecologically valid assessment of daily-life EF abilities of autistic children (as reported by their parents). The analyses showed that a strong majority of autistic children performed worse on the daily-life EF measure than the control group. These results agree with the previous studies showing a large discrepancy between lab-based and 'real-life' EF performance (Kenworthy et al., 2009). While these findings provide useful insights, the extrapolation of lab-based EF performance to daily-life functioning must be made cautiously. The tasks were administered and completed in a controlled stimuli-free environment, with sufficient rest time given between the tasks. In real-life settings, individuals with autism may face more complex demands, such as having to organise their thoughts and actions themselves while receiving various stimuli simultaneously, which can amplify EF difficulties. Therefore, the real-life applicability of these findings should be explored further in future studies.

Implications

The present study provides valuable insight into the inconsistencies in the literature examining EF strengths and difficulties in autistic individuals. These inconsistencies appear to stem, in part, from differences in task characteristics, with greater challenges with open-ended tasks compared to highly structured tasks, and in daily-life EF measures when compared to lab-based measurements (Williams & Jarrold, 2013). Furthermore, individual differences within the autism group. EF difficulties seem more strongly associated with more pronounced autistic behavioural characteristics.

Given the heterogeneity of EF profiles in autism, it is important to adopt an individual-focused approach. Rather than viewing the autistic population as a monolithic group with uniform challenges, recognising distinct cognitive profiles of individuals allows for more and better-tailored interventions. This perspective emphasises the importance of identifying specific EF strengths and weaknesses for each person, which can inform personalised strategies to manage difficulties. For example, some individuals may excel in tasks requiring focused attention or rule-based processing, while others might show stronger abilities in creativity or problem-solving when given more structure. By delineating these unique profiles, interventions can be designed to target specific areas of need while accommodating, or even leveraging, individual cognitive styles.

Importantly, this individual-focused perspective aligns with a strengths-based approach, which seeks to build upon an individual's inherent abilities rather than merely addressing difficulties. Instead of framing EF difficulties in autistic individuals purely in terms of challenges or limitations, this approach encourages practitioners to identify and nurture existing cognitive strengths. These strengths may include attention to detail, systematised thinking, or strong memory skills, which can be pivotal in shaping effective intervention programmes. Tailoring support programmes around both strengths and challenges not only foster a more empowering and inclusive model of care but also promotes a more comprehensive and all-encompassing view of EF development.

Limitations

This study has several limitations that should be acknowledged. First, the data were collected exclusively from Dutch-speaking participants, which may limit the generalisability of the findings to other populations or regions with different languages, cultures, and educational systems. Additionally, participants were recruited using somewhat different approaches. The non-autistic individuals were recruited from community-based contexts, including schools, personal contacts, and advertisements. The autistic participants were identified through the Autism Expertise Centre, a tertiary diagnostic setting within a university hospital, which could have introduced a bias toward more subtle presentations of autism. However, it is important to note that these children were not recruited in a hospital setting — they also attended schools and participated in everyday activities. The differences in recruitment approaches might have introduced some variability in the participants' experiences and characteristics, potentially influencing the results.

Another limitation concerns the sample's diversity. While participants were matched for gender ratio, age, and PIQ, such group comparisons excluded a part of autistic individuals who do not fall within this specific IQ and age range. Due to autism being very heterogeneous, excluding individuals with different cognitive profiles or co-occurring conditions limits the study's ability to capture the full spectrum of executive functioning in autism. A larger and more diverse sample could provide deeper insights into the distinct cognitive profiles of individuals with autism. Additionally, the relatively small sizes of clusters 1 and 2 (fewer than 20 participants) should be noted. Small sample sizes may affect the robustness of the findings and limit the statistical power to generalise the results. To validate the three EF subgroups identified, future research should include larger, more varied, and representative samples encompassing the broader autism spectrum.

A further limitation lies in the distinction between the BRIEF, which is based on parent (or teacher) reporting,

and the lab-based EF tasks completed by the participants themselves. Parent-reported measures like the BRIEF, while valuable for capturing real-life EF challenges, may introduce biases due to their subjective nature. Research indicates that parent ratings may reflect broader behavioural challenges influenced by contextual factors, such as expectations or situational interpretations (Bünger et al., 2019; Garagozzo et al., 2020; Hemmingsson et al., 2017; Kenny et al., 2024). Moreover, parent reports may not align with objective, performance-based assessments, often reflecting diffe aspects of EF (Eycke & Dewey, 2016; Toplak et al., 2008). This distinction between subjective and objective measures could influence the study's conclusions about executive functioning in real-life versus controlled settings. To address this issue, future studies should consider incorporating direct observations of participants in naturalistic settings, such as classrooms, to provide a more objective assessment of EF in real-world environments. Some studies (e.g., Tamm et al., 2020) have found stronger correlations between teacher ratings and observed student behaviour, highlighting the importance of triangulating data sources (Muñoz & Filippetti, 2019). Multi-method approaches that combine parent reports, direct observations and lab-based tasks could offer a more comprehensive understanding of EF across different contexts, reducing potential biases and enhancing the ecological validity of the findings (Nyongesa et al., 2019).

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Author contributions SS and LVE contributed equally to the work as joint first authors. SS: data analysis, article writing—original draft, writing—review and editing. LVE: conceptualisation, recruitment, methodology, data collection. EC: statistical guidance, writing—review and editing. IN: conceptualisation, methodology, supervision, writing—review and editing. DB: supervision, writing—review and editing.

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Data Availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Conflict of Interest The authors declare no competing interests.

Consent to Participate Informed consent was obtained from the participants' parents and participants aged 16 years and older.

Ethis approval The Study protocol was approved by the Medical Ethical Committee of the University Hospitals Leuven and the Social and Societal Ethics Committee (SMEC) of UK Leuven.

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