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ARTICLE

The structure of executive functioning in 11 to 14 year olds with and without special educational needs

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Abstract
The structure and development of executive functioning (EF) have been intensively studied in typically developing populations, with little attention given to those with Special Educational Needs (SEN). This study addresses this by comparing the EF structure of 132 adolescents (11–14 years-old) with SEN and 138 adolescents not requiring additional support (Non-SEN peers). Participants completed verbal and non-verbal assessments of key components of EF: inhibition, working memory and switching. Confirmatory Factor Analysis on each group tested one-, two- and three-factor models of EF. In both groups, there was statistical support for the fit of one- and two-factor models with no model being clearly better than the others; there was little support for three-factor models. Parsimony suggests that the one-factor model best represents the structure of EF. In light of our results, the implications for the nature of EF in early adolescence in both SEN and Non-SEN groups are discussed.

KEYWORDS
adolescence, confirmatory factor analysis, executive functioning, special educational needs

David Messer was the author of this manuscript, Jennifer Kearvall-White collected the data, carried out the analyses and her thesis chapter provided the basis for this article. The other authors made equivalent contributions and the order of their authorship is, therefore, alphabetical.

INTRODUCTION

Although many studies of executive functioning (EF) have been conducted, there is no one accepted definition of this construct (Diamond, 2013; Karr et al., 2018). This is partly due to the general view that EF involves a number of different but related components that contribute to higher level thinking processes (Miyake & Friedman, 2000). Despite differences in how the term is conceptualized, Karr et al. (2018) in their systematic review noted that some of the most commonly researched components of EF are: (1) inhibition, the suppression of strong internal predispositions to prevent incorrect or inappropriate responses; (2) shifting, the ability to rapidly change from one response to another using alternative strategies; and (3) updating/working memory, the temporary storage of information and its simultaneous manipulation. Each component develops according to its own schedule, marked by stages of acceleration and deceleration (e.g., Huizinga et al., 2006), with considerable individual differences across different measures of EF (Bull et al., 2008). Successful coordination of these three cognitive components allows individuals to make adaptive behavioural changes in their physical and social environments, and helps them adjust to new situations. Consequently, our working definition of EF is of a multifaceted cognitive skill that provides the basis for information processing involving inhibition, switching and updating/working memory. As such, EF contributes to the ability to carry out many higher level activities.

Understanding how the EF system unfolds during development is important given its potential effects on a wide range of key outcomes for children, including language (e.g., McClelland et al., 2007), mathematics (e.g., Cragg et al., 2017), literacy and reading comprehension (e.g., Messer et al., 2016), general school readiness and subsequent academic achievement (e.g., Cartwright, 2012; Stipek et al., 2010).

Many investigations have examined the development of EF in groups of individuals with a range of special needs. Often, these studies document lower EF performance by these groups in comparison to that of typically developing groups matched on appropriate indices (see Spaniol & Danielsson, 2022). Other studies have examined whether there are differences between these two groups in the relationship between EF and other abilities (e.g., Henry et al., 2012) or investigated whether subgroups can be identified (e.g., within unselected samples of children experiencing problems with attention, memory, language or school progress, Astle et al., 2019). However, there do not appear to be any studies concerned with the structural organization of EF in individuals with special educational needs. Knowing about this structure is not only of theoretical interest, but of relevance to whether therapeutic interventions are best targeted at specific components of EF.

Astle et al. (2019) have argued that more attention needs to be paid to heterogeneous groups of struggling learners. The current study addresses this recommendation and was designed to better understand the structural organization of EF in young adolescents with Special Educational Needs (SEN), compared to the EF organization of adolescents without SEN. Nearly a fifth of school students in England are judged in need of additional support for their education (Department for Education, 2020). During the period the current research was conducted, the term Special Educational Needs (SEN) was used in England (Ofsted, 2001) and students with SEN were identified according to three subgroups. When practitioners thought a pupil's cognitive performance (together with other indicators including behavioural issues) was comparable to that of the lowest attaining 10%–15% of an age group, that pupil received support though a procedure known as School Action. This involved school-initiated interventions and/or monitoring for the pupil, generally for up to one academic year. If progress was good, SEN status was revoked, but if there were continuing concerns, a move to the next level of support, termed School Action Plus (SA+) would trigger further assessment and support from external teaching services. It has been suggested that the attainment in this second group usually corresponded to that of the lowest 5% of an age group (Westerman et al., 2001). Children and young people in a third group with more complex, long-term needs involving multi-agency input were likely to have a statutory statement of special educational needs, and ability levels were likely to be the lowest attaining 2% of an age group. Thus, students with SEN were a heterogeneous group, with difficulties that varied in both extent and form. Since 2014, educational needs in the UK have been addressed by the Special Educational Needs and Disability (SEN[D]) system that is more flexible in terms of identification by parents, teachers and experts, such as an educational psychologist or health professional.

What is already known on this subject?

- Executive functioning is a key set of abilities related to cognitive development.
- Executive Functioning is generally considered to consist of executive functioning/updating, inhibition and switching.
- Executive functioning appears to progress from an undifferentiated set of abilities in pre-school to a more differentiated structure in adulthood.

What does this study add?

- Confirmatory factor analysis identified a one-factor model as providing the best structure of executive functioning in 11-14 year olds.
- A similar structure was found in students with special educational needs and those identified without these needs.
- Two-factor structures were acceptable in both groups and has similar fit indices to the one-factor models.

The SEN(D) provision has many similarities to the system used in the United States, although the latter identifies 13 areas of need and has an annual review. However, as the World Health Organization's (2011) report states 'There are no universally agreed definitions for such concepts as special needs education and inclusive education, which hampers comparison of data. The category covered by the terms special needs education, special educational needs and special education is broader than education of children with disabilities, because it includes children with other needs for example, through disadvantages resulting from gender, ethnicity, poverty, war trauma or orphanhood' (p. 209). The report also notes that assessment methodologies and practices differ widely between developed and developing countries (see also Kiru & Cooc, 2018). This suggests that care needs to be taken when extrapolating findings from one country to another.

In England, education in early adolescence (11–14 years) is often a time of transition, when students move from the supportive primary school environment to one with increased learning and social demands, together with expectations of greater independence. These increasing demands are likely to be especially difficult for students with SEN. At this age, EF is affected by developments in the frontal lobes (Blakemore, 2012) and there is a transitory increase in impulsivity (Anderson et al., 2001), and a lower level of cognitive flexibility compared to that of adults, even when there are minimal working memory demands (Davidson et al., 2006).

These considerations suggest that the organizational structure of EF in younger adolescents is worthy of investigation, as it might differ from the structure of EF in younger age groups and adults. In typically developing (TD) pre-adolescent children, there is support for a model that proposes a single undifferentiated structure of EF, particularly in the preschool age range (e.g., Hughes et al., 2010). There is less support for a one-factor model, however, with an increasing age (Lee et al., 2013; Messer et al., 2018; Miyake & Friedman, 2000; Wiebe et al., 2008), and it appears that two- or three-factor models are more often supported in adolescence and adulthood (see Figure 1 which shows a summary of 98 separate findings). However, there is variability in the findings so that at the same age it is not unusual for one-factor, two-factor and three-factor models of EF organization to be supported by different investigations. During early adolescence there is no consensus regarding a definitive organizational structure. There is support for one-factor structures (Xu et al., 2013; see Figure 2 for an example of this model), several different two-factor structures (Huizinga et al., 2006; Lee et al., 2013; St. Clair-Thompson & Gathercole, 2006; van der Sluis et al., 2007; see Figure 3 for an example) and three-factor models (Lehto et al., 2003; Rose et al., 2011; Wu et al., 2011; Xu et al., 2013).

Furthermore, neuro-constructivist perspectives (Karmiloff-Smith, 1998, Thomas et al., 2009) suggest that the organizational structure of EF in students with learning disabilities may differ from that

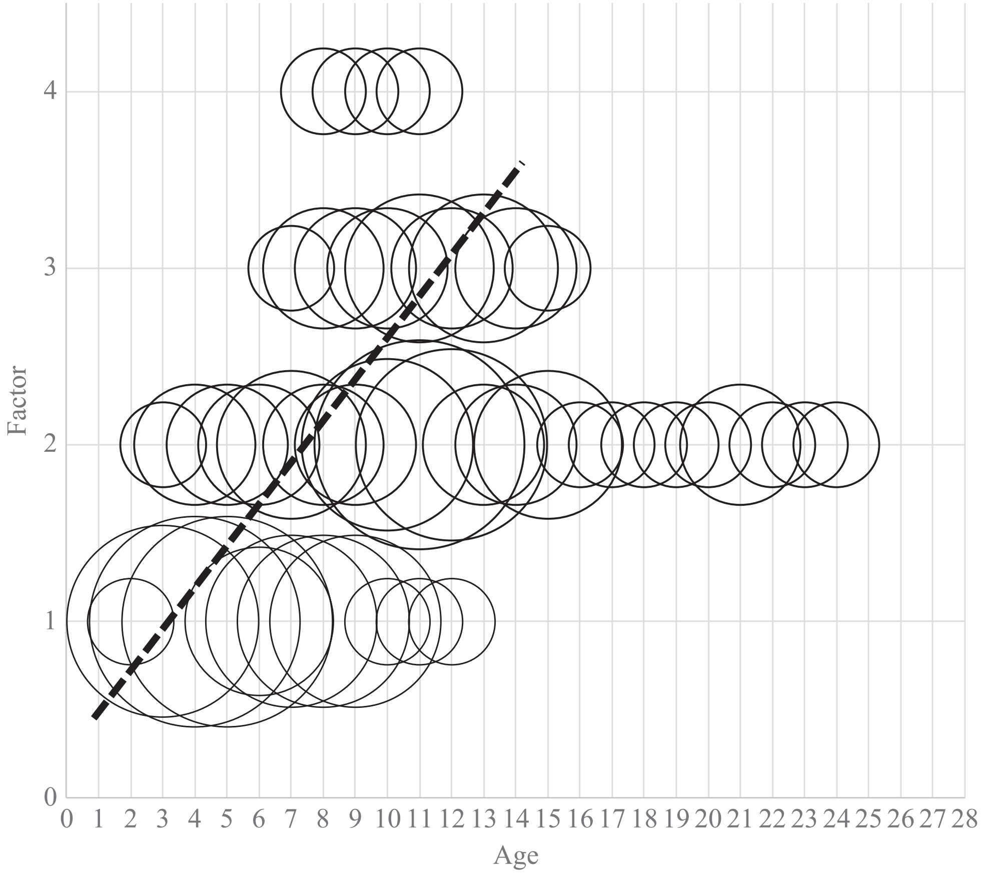

FIGURE 1 Evidence in support of one-, two-, three- and four-factor models of EF as a function of age, constructed from Lee et al. (2013), Karr et al. (2018), St. Clair-Thompson and Gathercole (2006) and the references therein. The size of the circles denotes the number of studies that have found support for a n-factor executive model at a particular age. The line of best fit goes through the weighted average of each group and shows a clear trend towards greater EF differentiation with age ($y = 0.22x + 0.32$, $R^2 = .21$)

of their TD peers. Consequently, there might be a different EF structure for students with SEN if they have followed a different developmental trajectory (Thomas et al., 2009). Alternatively, if there is merely a developmental delay rather than a qualitative difference, it might be predicted that the structure and organization of EF for SEN students is more likely to be similar to that of younger Non-SEN students. Given these alternative possibilities, two research questions were formulated:

Research Question 1: Does confirmatory factor analysis support the same one-, two- or three-factor EF structure in students with SEN and their Non-SEN peers aged 11–14 years?

Research Question 2: Is there evidence that during early adolescence, as in previous studies, the organizational structure of EF can be considered as part of a transition from childhood to adulthood?

METHOD

Participants

The participating students were from three academic years (11–14 years) and attended three mainstream schools from suburban, city outskirts and semi-rural catchment areas in England. Particularly

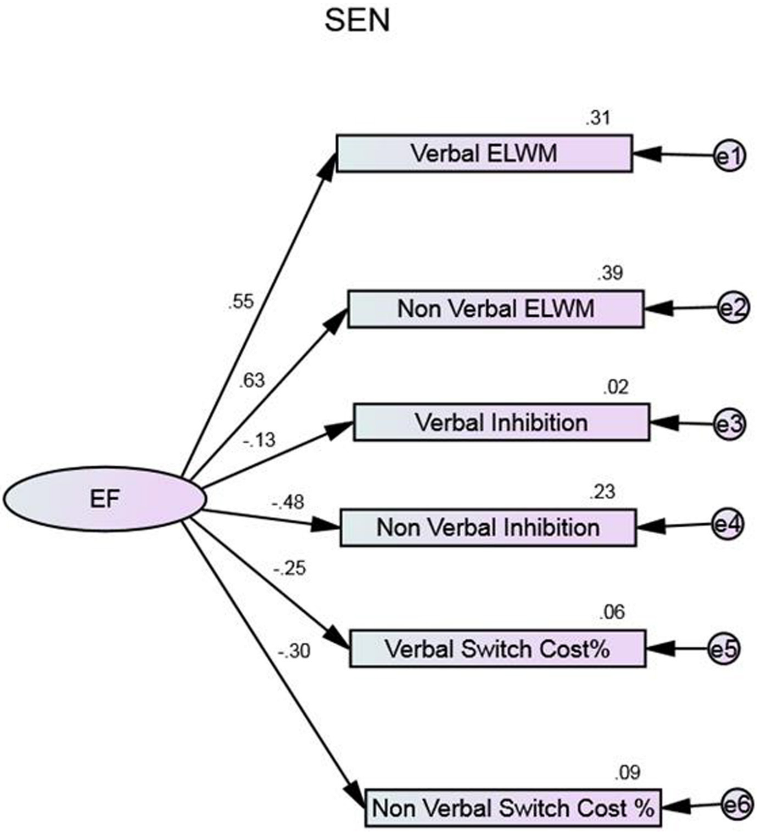

FIGURE 2 A one-factor model for the SEN group. Factor loadings between performance measures and the latent variables are indicated by a number next to an arrow. Variance is indicated by number above relevant box

vulnerable SEN students were excluded from recruitment by Special Educational Needs Co-ordinators because of concerns about safe-guarding. Parents of all Non-SEN peers were contacted about the possibility of their child participating in the study. There were no exclusion criteria for this group as the aim was to obtain a sample who were not identified in the educational system as having SEN. This resulted in the inclusion of some pupils who had scores below the typical range on the standardized tests that were administered.

One hundred and thirty-five students were recruited to the SEN group, one student with missing data was excluded from the Confirmatory Factor Ananlysis (CFA). One hundred and sixty-nine students were recruited to the Non-SEN group, there was missing data in 22 cases (due to recruitment constraints), and six students withdrew from the study, giving 141 students. In the whole sample, SPSS identified extreme outlier EF scores for three students (1.5 x interquartile range), and a further two students were identified by SPSS as having a large anomalous EF score. These five students (two SEN and three Non-SEN) were excluded from the CFA analyses.

Consequently, full data sets were collected from 132 SEN and 138 Non-SEN students. The SEN group had a mean age of 12 years 10 months, 30% were females; the Non-SEN group had a mean age of 13 years 3 months, 58% were females. Fifty-five percent of the SEN students were assigned to School Action, 29% to School Action Plus, and 15% had a statement. The school records indicated that the number of students with SEN who were identified with primary additional needs were as follows: 27 Specific Learning Difficulty; 19 Moderate Learning Difficulty; three General Learning Difficulty; five Behaviour Related; eight Autistic Spectrum Disorder; 12 Language related and Dyspraxia; eight Literacy and Dyslexia; 15 Other; 35 Not-specified.

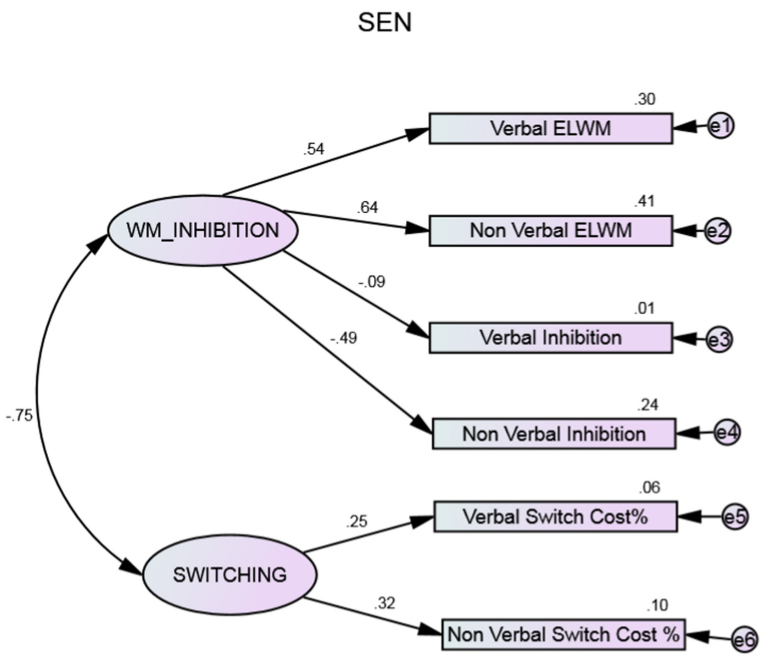

FIGURE 3 SEN group, the best fitting two-factor model 2b. Relations between latent variables are indicated by the curved arrow. Path relations between performance measures and the latent variables are indicated by a number next to an arrow. Variance is indicated by number above relevant box. WM refers to both forms of ELWM

TABLE 1 Descriptive statistics from standardized assessments and from EF tasks for SEN and Non-SEN groups

	SEN		NON-SEN	
	Mean	*SD*	Mean	*SD*
Standardized scores[a]				
Non-Verbal reasoning	82.4	15.7	99.1	15.5
Receptive vocabulary	87.7	15.3	99.6	13.3
Decoding	86.5	13.7	107.0	12.2
EF variables				
Verbal Inhibition (Errors)	8.4	5.2	6.7	3.8
Non-Verbal Inhibition (Errors)	6.5	4.0	3.6	2.8
Verbal Switching (Cost)	33.8	18.1	30.3	14.6
Non-Verbal Switching (Cost)	63.7	15.8	57.3	13.4
Verbal ELWM (Trials correct)	9.6	2.2	11.3	2.0
Non-Verbal ELWM (Trials correct)	11.0	3.5	14.1	3.6

[a]Non-verbal reasoning, Raven's Progressive Matrices (Raven et al., 2004); Receptive vocabulary, British Picture Vocabulary Scale (Dunn et al., 1997); Decoding, Test of Word Reading Efficiency (Torgesen et al., 1999).

Table 1 shows that the mean standardized scores of vocabulary, non-verbal reasoning and decoding for the SEN group were close to 85, that is, one standard deviation below the mean expected for their age, whereas the Non-SEN group had mean scores near to or above 100. T-tests revealed that there were significant differences between the two groups, although there was overlap in the ranges (vocabulary $t = 6.82$; ranges, SEN = 57–133, Non-SEN 74–142; non-verbal reasoning $t = 13.05$; ranges SEN 55–140; Non-SEN 60–145; decoding $t = 8.81$; ranges SEN 54–124, Non-SEN 81–134; for all comparisons $df = 268$; $p < .001$).

Ethical approval was granted by the relevant University Committee. Written informed consent from parents/guardians and written and verbal assent from students was gained prior to testing.

Standardized assessments of Non-EF abilities

The following three tests were administered to measure participants' verbal and literacy abilities as this study was part of a larger investigation. Raven's Progressive Matrices assessed non-verbal cognitive ability (RPM; Raven et al., 2004; note that the updated age-related norms were used from Raven, 2008). These matrices have a series of designs with a part missing and students select the correct part to complete each design from the options printed beneath. The British Picture Vocabulary Scale Second Edition (BPVS-2; Dunn et al., 1997) assessed receptive vocabulary; here, students select the appropriate picture from four possibilities that corresponds to a spoken word. The Test of Word Reading Efficiency (TOWRE; Torgesen et al., 1999) assessed decoding. This test includes both real word decoding (sight word efficiency using 104 real words) and non-word decoding (phonemic word efficiency using 63 non-words).

Assessments of executive function

We adopted a broad view of EF components by including measures, which generally are seen as reflecting key aspects of EF (e.g., Lehto et al., 2003; Karr et al., 2018). The measures concerned inhibition, switching, and the executive-loaded working memory (ELWM) element of the working memory system. Each EF component was assessed using a verbal and a non-verbal task. It should be noted that ELWM tasks are related to updating, a form of EF described by Miyake & Friedman (2012) and others, with the term 'working memory' (WM) being used to refer to constructs based on these tasks. 'Switching' is used to refer to processes that include 'shifting', as both invlve a change of attention and/or behaviour. The specific tasks were chosen because of a range of factors that included the availability of the test, the familiarity of the research team with the test, the suitability of the test for this age group (all the standardized tests covered the age range of the participants) and the ease of administration.

Verbal Inhibition (VIMI, Henry et al., 2012)

There are two parts to this test. First, in Part A, the experimenter says one of two words (e.g., 'doll' or 'car') and the student's task is to repeat the same word. After 20 repetitions, the student is required to respond with the alternative word for 20 repetitions. The process is repeated, totalling 80 repetitions. This entire sequence of copy/inhibit blocks is then repeated in Part B, with new stimuli (e.g., 'bus' and 'drum'). The number of errors in the second of the two sets of 20-word trials involving an alternative response was recorded. An error was considered to occur if the student's immediate response was anything other than the required alternative word. Cronbach's alpha, based on total error scores from Parts A and B is .727 (Henry et al., 2012).

Non-verbal inhibition, walk do not walk task (The test of everyday attention for children, Manly et al., 1999)

Students were given a marker pen and a response sheet containing 20 items or 'paths', each item containing 14 squares. Their task was to 'walk' along a path, taking steps by dotting a square each time they heard a 'go' tone' (from a CD). Between the 2nd and 12th steps along the path the tone unexpectedly ends differently (a 'no-go' tone), which is a signal not to mark the step/square. Errors were recorded to the 'no-go' tone (Mulder et al., 2011). Test–retest reliability is given as 71% in the manual.

Verbal ELWM, the listening recall task (Working memory test battery for children, Pickering & Gathercole, 2001)

Short sentences were spoken by the researcher and the student judged whether each was true/false. The student was then asked to recall the final word from each sentence in the correct order. The first six test trials had a list length of one item (i.e., only one sentence). There were six trials for each list length. When a student was correct on 4/6 trials they immediately progressed to a longer list. Testing was terminated when 4/6 trials at a list length were incorrect. Total trials correct were scored. Test–retest reliabilities of .38–.83 are reported (Pickering & Gathercole, 2001).

Non-verbal ELWM, odd-one-out task (Henry, 2001)

The Experimenter presented, to the student, three cards that each had a simple nonsense shape. The student pointed to the shape, which was the 'odd-one-out'. The student identified the odd-one-out for all the sets of cards at the same list length. Then the student was asked to point, in the correct order, to the location of each 'odd-one-out' in relation to a grid of three empty boxes on a response sheet; the number of grids on the response sheet corresponded to the number of sets of cards that had been presented. The first trial had one item, and the task progressed on to longer lists, with three trials per list length, until 2/3 trials were incorrect. Total trials correct were scored. Test-restest reliability is .80 (Henry, 2001).

Verbal switching (Delis–Kaplan Executive Function System D-KEFS, Delis et al., 2001)

Students were asked to name as many different kinds of fruits and then as many different pieces of furniture as they could in 60 seconds (simple fluency). Next they were asked to name and switch between these two categories in 60 seconds (e.g., apple, chair, orange, table). The switching score was the average raw score from the simple fluency task, minus the raw score from the switching task expressed as a cost percentage. Test–retest reliability is 0.53–0.65 (Delis et al., 2001).

Non-Verbal Switching, D-KEFS, Delis et al., 2001

Students were presented with a set of response boxes that contained five dots in each box. The student was asked to produce as many different shapes as possible by joining the dots in each box within 60 s. There were two simple tasks, one involving filled dots in the boxes and the other involving unfilled dots. The number of different shapes that students produced for each type of dot was recorded, and an average score was calculated. The students were then given response boxes, which contained five filled and five unfilled dots and asked to produce as many different shapes as possible by joining the dots in 60 seconds. When joining the dots the student had to alternate between filled and empty dots. Non-verbal switching 'cost' was the raw score from this condition minus the average from the two previous conditions, converted to a percentage. Test–retest reliability is reported as .13 (Delis et al., 2001).

Procedure

The tests were presented in two sessions of about an hour. The RPM and a questionnaire (not reported here) were completed in groups of approximately 30 students from the same classes. For the second session, students were collected at the end of a lesson and the walk to the research location helped to establish a relationship based on a relaxed but focused atmosphere. The order of tasks was: TOWRE, BPVS-2, Listening Recall, Odd-One-Out, Verbal Inhibition, Motor Inhibition, Verbal and Non-Verbal Fluency/Switch. Short breaks occurred between EF task pairs. Afterwards there was a debrief.

Data analysis, model testing and fit

Three different types of EF (inhibition, switching and working memory) were assessed, the verbal and non-verbal measures from these assessments were used to construct one-, two- and three-factor models of EF. The one-factor model involved all six assessments contributing to a single latent variable of EF (see Figure 2). Three different two-factor models were constructed. Each of the two-factor models was a different permutation: each permutation involved the association of two EF assessments in a single factor, with the third assessment being independent of these two. For example, see Figure 3, where the latent variables for Working Memory (WM) and Inhibition are associated, with Switching as a separate component.

Three, three-factor models were tested. Model 3a had latent variables involving Inhibition, WM and Switching; all three latent variables were related to one another, as identified by Karr et al. (2018) in a 'correlated factors' model. Model 3b corresponded to Miyake and Friedman's unity/diversity structure (Friedman, 2012), where all measures were linked to a common EF variable, but there also were two additional and separate latent variables involving shifting and updating/working memory. Model 3c had the three components linked to the relevant measures; and each component was then linked to a common EF latent variable (relevant figures are included in Appendix S1). All models were tested for each group separately.

To test each model, performance on the tasks were loaded on the appropriate latent factor. Confirmatory factor analyses (Amos 21) estimated goodness-of-fit indices of each model (Table 3). The maximum likelihood method was used to assess the overall fit of the models. The chi-square index of absolute fit gave the degree to which the covariance predicted by a specified model differed from observed covariance. A good fit is indicated by a small statistically non-significant chi-square value. The normed/relative chi-square value (X^2/df) is reported as it is sometimes used to adjust for sample size, although recommendations for acceptable figures range from 5.0 (Wheaton et al., 1977) to as low as 2.0 (Tabachnick and Fidell, 2007). The Root Mean Square Error of Approximation (RMSEA) also was examined with smaller values being more desirable (McQuitty, 2004), and Bentler's Comparative Index (CFI) was calculated as it can give assurance that the fit of a model is satisfactory (i.e., when above .95; Hu and Bentler, 1999). As the differences between most models were small on the basis of the fit indices, the Akaike information criterion (AIC) absolute fit index also was consulted because the difference in the chi-square values among models cannot always be interpreted as a test statistic (Schreiber et al., 2006). Smaller AIC values indicate a better fit.

When models returned unacceptable solutions, for example due to magnitude anomalies in covariance matrices, post hoc modifications were not conducted and the model was not considered to apply to the data. Parsimony was also considered, whereby a simpler model is considered a better description than a more complicated model (Blunch, 2008). However, it is arguable whether model selection on parsimony alone should be made as this involves disregarding more complex models. So, a prudent approach to evaluating and reporting model outcomes was adopted using these metrics.

RESULTS

Data preparation and correlations

Table 1 shows untransformed EF descriptive statistics. Inhibition measures were square-root transformed to correct positive skewness. After these transformations, all variables had normal distribution and had multivariate normality (for both groups and all the variables, skewness was <2, kurtosis <0.7 and Mardia's multivariate kurtosis <2.2).

Correlations between EF tasks are shown in Table 2. Both groups showed significant correlations between non-verbal inhibition and both forms of ELWM; and between verbal and non-verbal ELWM. In addition, there were several significant correlations that only occurred in one of the groups. In a number of other cases, the correlations were non-significant and below 0.10 indicating an absence of close relationships between EF variables.

Table 3 provides the goodness-of-fit statistics for all the models that were tested. The chi-square probabilities were acceptable for all the models, although this was marginal for model 3c in the SEN group. For those RMSEA values, which could be calculated, all were below .08 indicating acceptable fit. Similarly, Bentler's Comparative Fit Index indicated that all models had a good fit, except for models 3a and 3b in the SEN group. Thus, except for the three-factor model of the SEN group, all models were acceptable. We now consider which were the *best* fitting models and then the structure of these models for the SEN group and the Non-SEN group.

Model fit and structure

For the SEN group the one-factor model and a two-factor model 2b (Inhibition-WM and Switching) were considered to be the best fit (Table 3). The other two-factor models (2a, Inhibition-WM and Switching, 2c Switching-WM and Inhibition) returned acceptable fit indices, but they were not considered admissible because the covariance matrices were not positive definite, they contained zero or negative eigenvalues. There were concerns about all the three-factor models. Model 3a (three correlated factors) was inadmissible, the correlation matrices were not positive definite. Model 3b (unity–diversity) required adjustments to the error variances on all latent variables to enable the model to be statistically acceptable. However, this model was the poorest fit of all the models. Model 3c (three independent variables) required adjustment to Working Memory and Inhibition variables, but even so the chi-square probability and comparative fit index were poor (Table 3). Consequently, the support for three-factor

TABLE 2 Correlations between EF variables in the Non-SEN and SEN groups

	Inhibition	Switching			ELWM	
EF variables	**Verbal**	**Non-V**	**Verbal**	**Non-V**	**Verbal**	**Non-V**
SEN group						
Verbal Inhibition	1					
Non-Verbal Inhibition	.008	1				
Verbal switching	.154	.112	1			
Non-Verbal switching	.085	.054	.081	1		
Verbal ELWM	−.019	**−.268****	−.102	**−.179***	1	
Non-Verbal ELWM	−.063	**−.330****	−.098	−.153	**.340****	1
Non-SEN group						
Verbal inhibition	1					
Non-Verbal inhibition	**.180***	1				
Verbal switching	.049	.065	1			
Non-Verbal switching	.023	.103	−.002	1		
Verbal ELWM	.001	**−.207****	.038	−.043	1	
Non-Verbal ELWM	**−.150***	**−.281****	.003	−.120	**.318****	1

Note: Significant correlations are in bold.

*p < .05; **p < .01.

TABLE 3 CFA goodness-of-fit indices for one-, two- and three-factor models in the SEN and Non-SEN groups

Model	[a]X^2	*Df*	*p*	X^2/df	[b]RMSEA (90% CI)	[c]CFI	[d]AIC	Comments
SEN Group								
One Factor	5.23	9	.81	.58	0 (0/0.06)	1.00	29.22	**Most parsimonious acceptable model**
Two factors								
2a. Switch-Inhib + Working Memory	5.05	8	.75	.63	0 (0/0.07)	1.00	31.04	*Solution not admissible*
2b. WM-Inhib + Switching	5.06	8	.75	.63	0 (0/0.73)	1.00	31.05	**Only acceptable two-factor model**
2c. Switch-WM + Inhib	4.91	7	.76	.61	0 (0/0.07)	1.00	30.90	*Solution not admissible*
Three factors								
3a. Three correlated factors	4.66	6	.59					Solution not admissible
3b. Unity Diversity	8.47	10	.58	.84	0 (0/0.08)	1.00	30.47	All factors needed adjustment
3b. Independent factors	14.7	8	.06	1.84	0.08 (0/0.14)	0.79	31.43	WM and Inhibition adjusted
Non-SEN group								
One factor	5.38	9	.80	.58	0 (0/.06)	1.00	29.38	**Most parsimonious acceptable model**
Two factors								
2a. Switch-Inhib + WM	3.56	8	.89	.44	0 (0/0.05)	1.00	29.56	Best fitting two-factor model using X^2/df value
2b. WM -Inhib + Switch	5.40	9	.79	.60	0 (0/0.06)	1.00	29.40	Acceptable model, lowest two factor AIC index
2c. Switch-WM + Inhib	3.63	8	.88	.45	0 (0/0.47)	1.00	29.63	Acceptable model
Three factors								
3a. Three correlated factors	3.41	6	.57		0 (0/0.06)	1.00		Solution not admissible
3b. Unity diversity	5.64	9	.77	.62	0 (0/0.06)	1.00	29.65	All factors needed adjustment
3b. Independent factors	3.43	7	.84	.49	0 (0/0.06)	1.00	31.43	Switch adjusted

Note: Best fitting models in bold. WM latent factor contains both forms of ELWM.

[a]Chi-square values with $p > .05$ indicate acceptable model fit.

[b]RMSEA values below .08 indicate a satisfactory fit.

[c]CFI Bentler's Comparative Fit Index, which takes account of the parsimony of a model and sample size, values higher than .95 indicate good fit.

[d]AIC, Akaike's Information Criterion, low values indicate best fit.

TABLE 4 Group parameter estimates: One-factor model for SEN and Non-SEN groups

	β		*B*		*SE*	
Observed variable	**SEN**	**Non-SEN**	**SEN**	**Non-SEN**	**SEN**	**Non-SEN**
Verbal ELWM	0.55	0.45	1	1		
Non-Verbal ELWM	0.63	0.66	1.88**	2.77**	0.58	1.07
Verbal Inhibition	−0.13	−0.16	−0.08	−0.19	0.09	0.11
Non-Verbal Inhibition	−0.48	−0.45	−0.36**	−0.43**	0.11	0.15
Verbal switching	−0.25	−0.01	−3.00	−0.25	1.82	1.83
Non-Verbal Switching	−0.30	−0.14	−3.29*	−2.46	1.64	1.79

Note: *β* standardized regression weights as described in the figures.
Abbreviations: *B*, Beta; *SE*, standard error of beta.
*$p<.05$; **$p<.01$; ***$p<.0.001$.

TABLE 5 SEN group model 2b, factor loadings and parameter estimates for best fitting model of WM-inhibition and switching

Observed variable	**Latent construct**	***β***	***B***	***SE***
Verbal ELWM	WM-INHIB	0.54	1	
Non-Verbal ELWM	WM-INHIB	0.64	1.89*	0.59
Verbal Inhibition	WM-INHIB	−0.09	−0.07	0.09
Non-Verbal Inhibition	WM-INHIB	−0.49	−0.36*	0.11
Verbal Switching	SWITCHING	0.25	1	
Non-Verbal Switching	SWITCHING	0.32	1.11	0.82

Note: *β* loadings from standardized regression weights.
Abbreviations: *B*, Beta; *SE*, standard error of beta.
*$p<.05$;

models was weak. Overall, for the SEN group the one-factor model was a better fit than model 2b: the chi-square significance value was slightly higher; the AIC was slightly lower; and the model was more parsimonious.

Details about the structure of the one-factor model for the SEN group are shown in Figure 2 and the group parameter estimates are given in Table 4. Verbal and Non-verbal ELWM together with Non-verbal Inhibition had the highest factor loadings suggesting that these variables were the most relevant and inter-related components of EF at this age. The weakest loading was provided by Verbal Inhibition suggesting this was a minor component of the EF latent variable.

Model 2b (WM-Inhibition and Switching) was the only admissible two-factor solution for the SEN group (Figure 3 and Table 5). In Model 2b the association between the two factors was strong (−0.75), indicating close links between the two latent variables. The WM-Inhibition factor had reasonable factor loadings from three of the four components, with a very weak loading from Verbal Inhibition as in the one-factor model. For the latent variable of Switching there were relatively weak factor loadings from both Verbal and Non-Verbal Switching, and these were similar to those in the one-factor model. Thus, there were not large differences in the structure of the two acceptable models for the SEN group (the one-factor model and Model 2b); both involved important contributions to latent variables from Verbal and Non-Verbal ELWM and from Non-Verbal Inhibition.

For the Non-SEN group there were similarities in the size of the statistics about fit to those of the SEN group (see Table 3). All the one- and two-factor models produced admissible solutions and no model was clearly better than the others across all the fit statistics. This means, according to parsimony, the one-factor model should be selected as the best fitting model. However, it should be noted that the statistics about fit in Table 3 show that although the one-factor model had the lowest AIC index, this

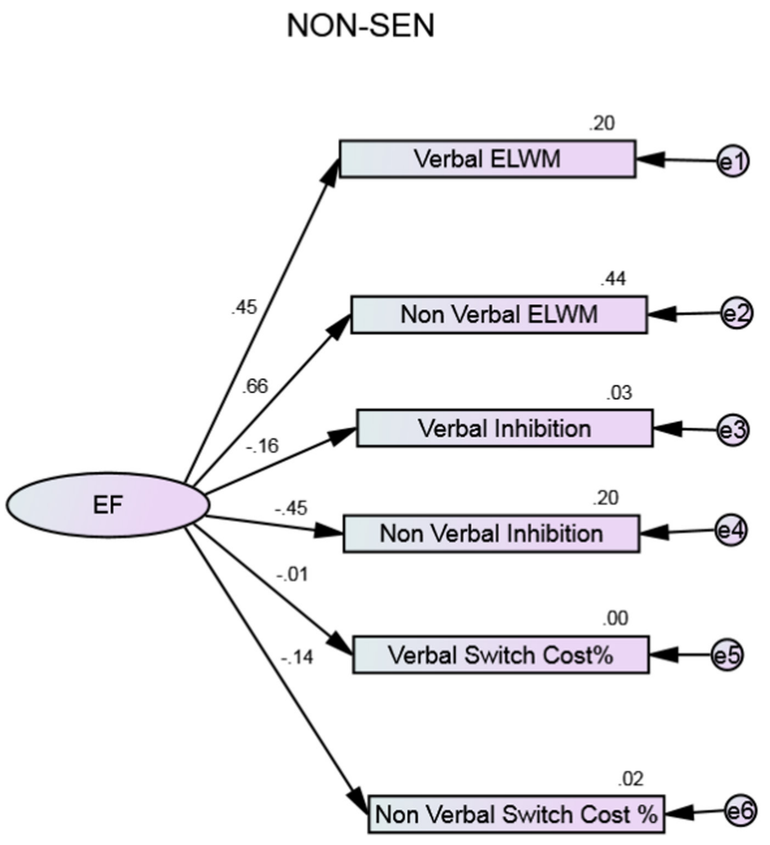

FIGURE 4 A one-factor model 1 for the non-SEN group. Path relations between performance measures and the latent variables are indicated by a number next to an arrow. Variance is indicated by number above relevant box

only was just lower than that of Model 2b. Furthermore, Models 2a and 2c had the best chi-square significance values, with Model 2a having the best value of all. Thus, the statistics about fit do not indicate that the one-factor model was clearly better than two-factor models. The three-factor models were a poor fit for the Non-SEN group, as for the SEN group; model 3a was inadmissible, model 3b had the worst fit of all, and model 3c needed adjustments to Switching, but this still resulted in the model having the poorest AIC in the Non-SEN group.

Further details about the structure of the one-factor model for the Non-SEN group are shown in Figure 4. The structure is similar to that of the SEN group as Verbal ELWM, Non-Verbal ELWM and Non-verbal Inhibition had the highest factor loadings in both groups (standardized regression weights; Table 4). In contrast, there were low loadings for Verbal Inhibition, Verbal Switching and Non-Verbal Switching, as in the SEN group. This suggests that both forms of ELWM and Non-verbal Inhibition were the most important contributors to EF structure in early adolescence. An analysis confirmed group invariance and, therefore, a lack of difference between groups in the organization of EF in the SEN and Non-SEN one-factor models ($\chi^2_{\text{difference}}$ [$df_{difference}$ = 5] = 4.571, p = 0.47).

Figure 5 and Table 6 provide information about Model 2a, which had the highest chi-square significance value for the Non-SEN group. This model involved a latent variable of Switching and Inhibition and a separate latent variable of Working Memory. The two latent variables were related to one another (.62) and like the other models so far discussed the highest factor loadings involved Verbal ELWM, Non-Verbal ELWM and Non-verbal Inhibition, although in this case the contributions of ELWM and Inhibition were to different latent variables.

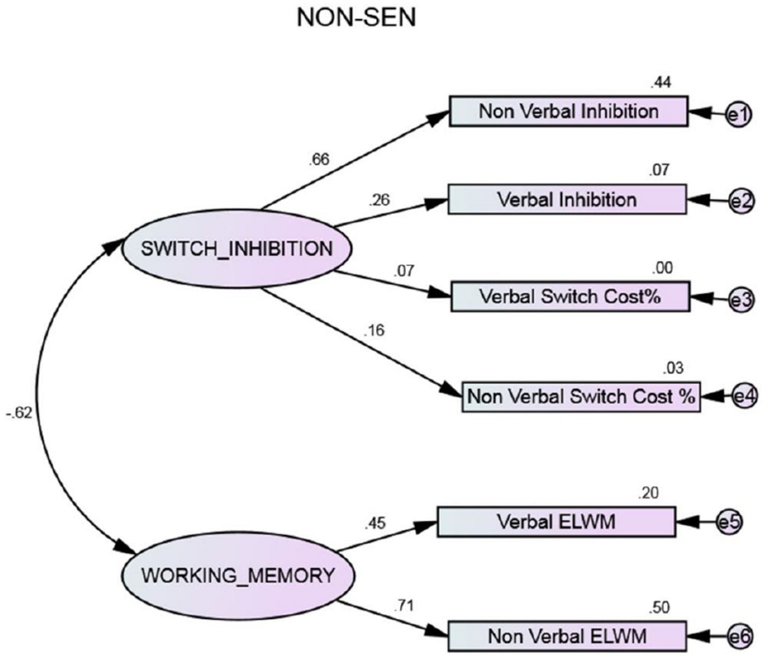

FIGURE 5 Non-SEN group, two-factor model 2a. Relations between latent variables indicated by the curved arrow. Path relations between performance measures and the latent variables are indicated by a number next to an arrow. Variance is indicated by number above relevant box. Working memory latent factor contains both forms of ELWM

TABLE 6 Non-SEN factor loadings and parameter estimates for best fitting two-factor model (2a) of switching-inhibition and WM

Observed variable	Latent construct	*β*	*B*	*SE*
Verbal Inhibition	SWITCH-INHIB	0.66	1	
Non-Verbal Inhibition	SWITCH-INHIB	0.26	0.37	0.23
Verbal Switching	SWITCH-INHIB	0.07	1.81	3.101
Non-Verbal Switching	SWITCH-INHIB	0.16	3.84	3.24
Verbal ELWM	Working Memory	0.45	1	
Non-Verbal ELWM	Working Memory	0.71	2.88*	1.28

*$p < .05$.

DISCUSSION

Our first research question concerned whether confirmatory factor analysis supported the same one-, two- or three-factor EF structure in students with SEN and their Non-SEN peers. The analyses revealed that: the one-factor model was acceptable in both groups; Model 2a was acceptable in the SEN group, while in the Non-SEN group all two-factor models were acceptable; and all the three-factor models gave the poorest fit in both groups. This indicates a reasonable degree of similarity in the findings about the structure of EF between the SEN and Non-SEN groups. This similarity occurred despite the presence of significant differences in the EF abilities between these two samples (Kearvell-White, 2020) and suggests that in the SEN group, the organization of EF is similar to the Non-SEN group, rather than different.

Which model best represents EF structure in the two groups? The one-factor model had the best chi-square significance value for the SEN group; the lowest AIC index for both groups; and was also the most parsimonious model. Consequently, there are reasonable grounds to select the one-factor model as best representing the structure of EF in the SEN and Non-SEN groups. A one-factor model suggests that most components of EF in early adolescence contribute to a common latent variable and that there is more unity than diversity. However, in both groups the fit indices for the one-factor model were not very different to those of some two-factor models; the one-factor model only had marginal superiority according to some fit indices and not for all the fit indices.

In both groups, the most important contributions to the EF latent variable for the one-factor model came from Verbal ELWM, Non-verbal ELWM and Non-verbal Inhibition. As might be expected, for most two-factor models, the same set of variables made the most important contribution to the latent EF variables. Previous research on young children by Wiebe et al. (2008) has also identified relations between working memory and inhibition, while research on 11–12 year olds has identified relations between updating and inhibition (St. Clair-Thompson & Gathercole, 2006). Both Working Memory and Inhibition involve the ability to inhibit actions or cognitive processes (Anderson, 2002) and shared cognitive processes may be responsible for these relations (St. Clair-Thompson & Gathercole, 2006).

Switching often had lower factor loadings than the other variables. In previous research involving comparisons of typically developing young people and those with disabilities, significant differences between these groups have been reported in Working Memory and Inhibition, but often there was no significant difference in Switching (e.g., Kirke-Smith et al., 2016). Consequently, it may be that switching is less central to a range of EF abilities at this age or that our measures of switching are less appropriate (Xu et al., 2013). In relation to this, it is worth noting that the correlation coefficients between verbal and non-verbal switching in both groups were below .10, a finding that raises questions about the switching measures and is an issue, which needs further research (see Cepeda et al., 2001).

These findings about one- and two-factor models are also relevant to our second research question concerning whether, during early adolescence, there is evidence that the organizational structure of EF could be considered as part of a transition from childhood to adulthood. Although parsimony suggests that the one-factor model is the best description of EF structure in the two groups, our analyses also revealed that there were not large differences in the acceptability of the one- and two-factor models, and in some cases, the two-factor models had slightly better fit indices. In this respect the findings can be interpreted as compatible with early adolescence being a transitional age in the development of EF structures towards a more differentiated structure.

In general, there is more support for two- or three-factor models during early adolescence (Figure 1; Huizinga et al., 2006; Lee et al., 2013; Lehto et al., 2003; Rose et al., 2011; Wu et al., 2011). However, Xu et al. (2013) reported that a one-factor model best fitted the data from 7–9 and 10–12 year olds, whereas a three-factor model was best for 13–15 year olds. Therefore, although the one-factor model might be considered the best fitting for our data, the presence of similarly acceptable two-factor models is consistent with previous findings of a differentiation of EF around adolescence. Further, it should be acknowledged that a limitation of our research is the choice of EF variables, and a larger or different set of variables might have identified other structural models as having the best fit.

The idea of a transition during adolescence in EF development is supported by neurological changes in the brain, particularly those areas associated with the prefrontal cortex (Blakemore & Mills, 2014; Zelazo et al., 2016). Both EF and the prefrontal cortex continue to mature well into adolescence (Anderson et al., 2001; Downes et al., 2017). Furthermore, during adolescence the differentiation of functions through neural specialization appears to lead to more efficient processing of the complex skills associated with EF such as those that require monitoring performance, feedback learning and relational reasoning (Crone & Dahl, 2012) as well as the integration of more contextual information, which permits increased cognitive flexibility for decision-making in accomplishing novel tasks (Steinbeis & Crone, 2016). During adolescence there are also increased levels of processing speed afforded by myelination; and greater efficiency resulting from synaptic pruning of unused connections (Blakemore & Choudhury, 2006, Blakemore, 2012).

CONCLUSIONS

There are several arguments, including parsimony, to support the idea of a one-factor model being the most appropriate structure of EF for our data about younger adolescents, particularly for the SEN group. Therefore, EF as a unitary function can be cautiously advanced as the best model for early adolescence, and that a similar structural organization was present for SEN and Non-SEN groups. However, all the two-factor models were acceptable in the Non-SEN group, and one of them was acceptable in the SEN group. Therefore, there was also evidence to support some differentiation of EF abilities into two factors. This differentiation is a reasonable expectation from previous findings of a trend across the lifespan from one-factor structures in pre-adolescence to more complex structures in later adolescence and adulthood.

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CONFLICT OF INTEREST

We have no conflicts of interest to disclose.

AUTHOR CONTRIBUTIONS

David Messer: Conceptualization; methodology; supervision. **Jennifer Kearvell-White:** Conceptualization; investigation; methodology. **Henrik Danielsson:** Conceptualization; methodology; supervision. **Dorothy Faulkner:** Supervision. **Lucy Henry:** Conceptualization; methodology; supervision. **Paul Ibbotson:** Supervision.

DATA AVAILABILITY STATEMENT

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

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