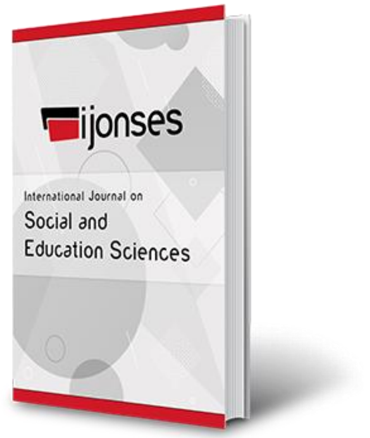

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The Deficit in Visuo-spatial Working Memory in Dyslexic Population? A Systemic Review and Meta-analysis

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The Deficit in Visuo-spatial Working Memory in Dyslexic Population? A Systemic Review and Meta-analysis

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Abstract

Development dyslexia (DD) is a common language disorder, that significantly affects children. Despite having ordinary intelligence, dyslexic people struggle with reading, writing, and comprehension in their native tongue. It is still unclear whether dyslexic kids have difficulties with visuo-spatial working memory. Using meta-analysis, this gap was filled. Applying a Boolean search on Web of Science was necessary to find the pertinent papers. Thirteen studies were analyzed. The average, standard deviation, and sample size for each task were extracted. There were large effect sizes between children with DD and their age-matched peers in terms of their visuo-spatial working memory. The findings imply that visuo-spatial working memory deficiencies in dyslexic children indicate that dyslexia might exhibit domain-general characteristics. We discovered during our research that the type of language used and the testing procedure could have an impact on the test outcomes. Therefore, future research should focus on the type of tasks or language.

Introduction

Working memory is the cognitive system where information is stored and processed temporarily during complex cognitive tasks (A. Baddeley, 2000). Working memory has three subcomponents, namely the central executive (CE), the phonological loop (PL), and the visuospatial sketchpad (VSSP). The PL and VSSP are the two slave systems, which are also called short-term memory. The supervisory system is CE which has responsibility for controlling and manipulating the information stored in two subordinate systems (A. Baddeley, 1996, 2003), which is important in skills such as chess playing (A. Baddeley, 1992). It is usually related to the frontal lobe functions (A. Baddeley, 1996, 2003). The PL is dedicated to the temporary storage of verbal information as a peripheral system, and the VSSP is a limited capacity slave system designed for the temporary storage of visuo-spatial information (Moura et al., 2015).

It has been suggested that working memory plays a crucial role in language processing (Gray et al., 2019). Verbal working memory has long been studied, whereas visuo-spatial working memory had not attracted great attention until the model of working memory proposed by Baddeley (1986). According to this model, visuo-spatial working memory (VSWM) is associated with perceptive-motor tracking (A. Baddeley et al., 1973; A. D. Baddeley & Lieberman, 2017), planning and preservation of motion sequences (Quinn & Ralston, 1986; Smyth & Pendleton, 1989, 1990), visual image generation and memory (A. Baddeley et al., 1973), etc. Assessment of the working memory capacity comprises an important part in measures of children's cognitive capacity (Gray et al., 2019). Indeed, impairment of WM has been observed in many language disorders, such as in developmental language disorder (DLD) (A. Baddeley, 2003; Ebert & Kohnert, 2011). Developmental dyslexia is arguably also one of the disorders which can be defined via working memory capacity (Moura et al., 2015).

Developmental dyslexia (DD), as a neurological disorder of genetic origin, has specific effects on reading (Galaburda et al., 1985). Dyslexic people have difficulty in reading, writing, and comprehension in their native language, although they have average intelligence. The growing research provides evidence that dyslexic children show deficits in verbal working memory (Menghini et al., 2011; Swanson et al., 2009; Wang & Gathercole, 2013; Willcutt et al., 2005). However, various recourses are utilized in visuo-spatial cognition and the auditory-verbal domain (Duff & Logie, 1999). Indeed, there is no consistency regarding whether the DD population have impairments in VSWM. Some studies evidenced the children with DD had substantial impairments in processing and memorising visuo-spatial materials (Menghini et al., 2011; Swanson et al., 1996, 2009; Wang & Gathercole, 2013). Tracy's (2017) research has shown that dyslexic children rely more on visual skills in spelling. Due to the conclusion, we can infer the children with DD have minor impairment on VSWM. Other studies found no significant deficit in VSWM of the DD population (Jeffries & Everatt, 2004).

To summarise, challenging to our understanding is by the inconsistencies across studies. A meta-analysis was conducted to address this research gap to analyse the statistical data and expand conclusions drawn from studies with small numbers of participants. Meta-analysis provides greater statistical power and more confirmatory data analysis to extrapolate to the general population. To our knowledge, Swanson studied this topic with a meta-analysis in 2009 without an absolute answer. Moreover, recent research on the VSWM capacity of the dyslexic population still has not offered a definite conclusion. Therefore, a new meta-analysis is indispensable to explore whether dyslexic children have deficits in VSWM.

Hence, the current study investigated whether dyslexic children have deficits in VSWM than their typically developing children. It was hypothesized that the VSWM capacity of a healthy population is better than the of dyslexic children.

Method

Inclusion Criteria

(1) Children with Development Dyslexia (DD) were included, who should previously be diagnosed with DD by experts such as child psychiatrists, developmental pediatricians, psychologists or child neurologists, whose score at reading fluency and accuracy measure was lower than the other children at the same age.
(2) A group of typically developing control (TD) was included, with either age or language skills matched.
(3) Participants in the original study should be under 18.
(4) There were no restrictions regarding the participants' country, race, gender, and publication language.

Search Methods for Identification of Studies

Database

Due to time and effort limits, studies were identified only in Web of Science. Web of Science is an extensive, comprehensive, multidisciplinary database of core journal literature indexes, including science, social sciences, and the arts and humanities.

Boolean Search Phrase

We used Boolean search strategy to search for relevant records. A series of synonyms used to refer to DD and VSWM were included in the Boolean phrase to find the broadest possible range of research. It excludes research terminology, acquired language difficulties, case studies and studies on adults. The search terms are listed below:

> (ALL=("developmental dyslexia") OR ALL=(dyslexia) OR ALL=(DD) OR ALL=(dyslexic)) AND (ALL=(visuo-spatial working memory capacity*)OR ALL=(visual working memory capacity*)OR ALL=(visuo-spatial working memory measure*) OR ALL=(visuo-spatial working memory assessment*)) NOT ALL=(comorbid*)

Data Collection and Analysis

Selection of Studies

To select appropriate articles, the inclusion criteria were applied. We first scanned the titles and abstracts of the identified records and then read the full texts of the remaining articles. The bibliographies of the studies which were included were read carefully for additional references (see Figure 1).

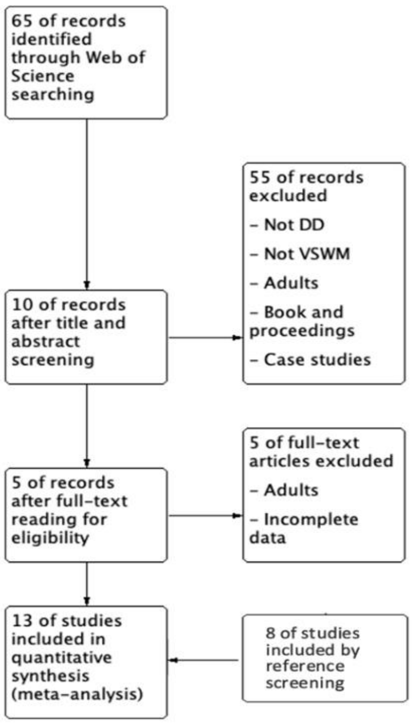

Figure 1. The Sections Are Processed by a Flow Diagram

Reliability of Study Selection

The first author selected the abstract and the full text independently. The second author completed the examination of the studies.

Data Extraction

Data from the 13 selected studies were entered into a spreadsheet (see Appendix A) guided by the PRISMA statement (Moher et al., 2009). The characteristics form included general information from each study (e.g. first author, publication year, language, and country of study), age and inclusion criteria of the DD population recruited, and task for VSWM assessment.

The data necessary for the computation of effect sizes were extracted at this stage: the mean, standard deviation, task type, control type and sample sizes of at least one group of children with DD and a group of controls. At the same time, at this stage, we identified missing data and further excluded 21 studies. This data extraction yielded 17 research findings from 13 studies. The results are summarised in Appendix B.

Validity Assessment

The data extraction grid also included a quality assessment section according to the Critical Appraisal Skills Programme list based on the cohort studies (Critical Appraisal Skills Programme, 2017). The results of the validity assessment are shown in Appendix 3.

Computation of the Effect Sizes

Hedge's g was used to calculate the effect size for each research finding (Borenstein et al., 2021). In the current meta-analysis, the DD group mean was always subtracted from the TD group mean. To maintain consistency in the meta-analysis, when the number of errors were used to indicate the scores, inverted mean scores (e.g., $M = 1$ becoming $M = -1$) was used as recommended by Lipsey and Wilson (2001).

Data Analysis

The data were analysed using the Review Manager (Version 5.4; The Cochrane Collaboration, 2020.)

Assessment of Heterogeneity

Heterogeneity refers to the difference in effect size among the study samples. Following Tawfik (2019), an indicator of heterogeneity is I^2, together with the Tau^2, its p-value, and Chi^2. It is expressed in the percentage of total variability attributable to heterogeneity. Indicative I^2 values of 25%, 50%, and 75% were used to benchmark the studies' heterogeneity as low, moderate, or high (Higgins, Thompson, Deeks, & Altman, 2003).

Assessment of Reporting Biases

Following Tawfik (2019), publication biases were checked using funnel plots. Asymmetry in the funnel plot would suggest a significant publication bias.

For all presented analyses, a sensitivity analysis was performed to examine the impact of the potential outliers on the effect size estimates and heterogeneity. Removing each research from the model, the model was applied to all other studies. One outlier was indeed discovered: when Attree (2009) was removed from the model, the results were changed significantly. Hence, this article was removed from the analysis.

Choice of Statistical Model

Given the high heterogeneity of the studies included and chosen a random-effects model to conduct the statistical analysis.

Results

From Figure 2, we can see 16 studies and their respective OR (95% CI). The random-effect model revealed a significant effect (Z = 2.76, p = 0.006) and a large effect size indicating that the DD group perform worse than their TD peers (OR = -0.33, 95% confidence interval (CI) [-0.57, -0.10]).

	DD			TD				Std. Mean Difference	
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**	**Year**
Alloway 2017	95.38	18.55	24	102.86	19.25	50	6.5%	−0.39 [−0.88, 0.10]	2017
Moura,O 2015	7.18	1.53	50	7.74	1.93	50	7.2%	−0.32 [−0.71, 0.08]	2015
Moura, O 2015	15.25	5.67	50	15.86	5.77	50	7.3%	−0.11 [−0.50, 0.29]	2015
Booth 2013	6.57	2.06	21	6.38	1.2	21	5.7%	0.11 [−0.49, 0.72]	2013
Luo, Y 2013	3.5	1.24	15	3.4	0.83	15	5.0%	0.09 [−0.62, 0.81]	2013
Wang 2013	96.74	14	46	105.11	12.56	45	7.0%	−0.62 [−1.04, −0.20]	2013
Menghini2011	9.2	2.9	28	14.7	6.2	22	5.7%	−1.17 [−1.77, −0.56]	2011
Menghini 2011	9.7	2.4	26	15.7	5.5	24	5.6%	−1.41 [−2.04, −0.79]	2011
Attree2009	14.61	0.56	21	12.67	0.45	21	0.0%	3.75 [2.71, 4.78]	2009
Kibby2008	102.61	12.24	23	103.5	11.61	30	6.1%	−0.07 [−0.62, 0.47]	2008
Kibby 2008	94.78	11.43	23	96.83	11.63	30	6.1%	−0.17 [−0.72, 0.37]	2008
Marzocchi 2008	−16.5	1.34	22	−21.3	6.8	30	5.9%	0.90 [0.32, 1.48]	2008
Willcutt 2005	−46.2	19.6	109	−37.2	16.4	151	8.2%	−0.50 [−0.75, −0.25]	2005
Jeffries2004	4.05	0.67	21	4.25	0.74	40	6.2%	−0.28 [−0.81, 0.26]	2004
Jeffries 2004	4.14	1.39	21	4.35	1.27	40	6.2%	−0.16 [−0.69, 0.37]	2004
Swanson 2001	3.87	1.31	16	3.9	1.2	20	5.3%	−0.02 [−0.68, 0.63]	2001
Swanson1996	2.81	0.95	22	4.02	1.08	34	5.9%	−1.16 [−1.74, −0.58]	1996
Total (95% CI)			**517**			**652**	**100.0%**	**−0.33 [−0.57, −0.10]**	

Heterogeneity: $Tau^2 = 0.16$; $Chi^2 = 54.57$, df = 15 (P < 0.00001); $I^2 = 73\%$
Test for overall effect: Z = 2.76 (P = 0.006)

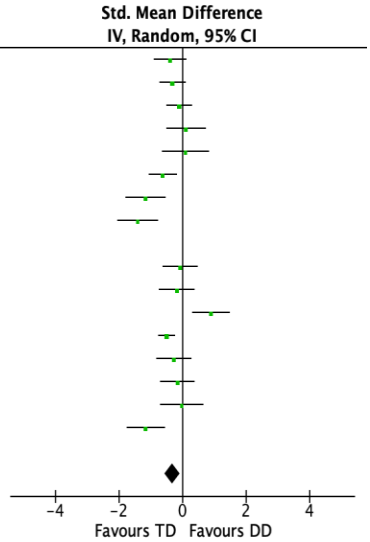

Figure 2. Random Effect Model Forest Plot for Comparison between DD and TD

However, heterogeneity was large ($I^2 = 73\%$), $Tau^2 = 0.16$, $p < 0.00001$, indicating unidentified sources of variability. There did not detect publication bias (see Figure 3).

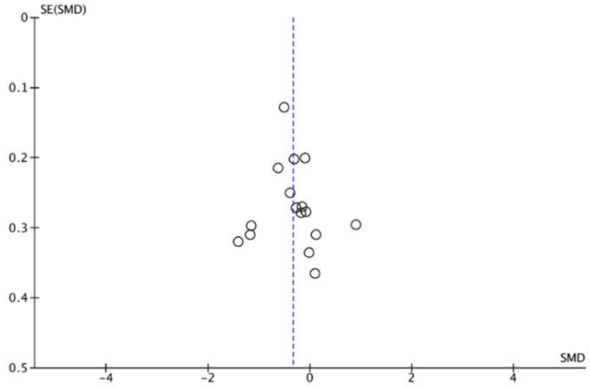

Figure 3. Funnel Plot of the Publication Bias for Comparison between DD and TD

When the two studies with Chinese were moved, from Figure 4, the random-effect model a significant effect (Z = 2.51, p = 0.01) and large effect size in favour of the DD group (OR = -0.33), 95% confidence interval (CI) [-0.60, -0.07].

	DD			TD				Std. Mean Difference	
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI	Year
Alloway 2017	95.38	18.55	24	102.86	19.25	50	7.4%	−0.39 [−0.88, 0.10]	2017
Moura,O 2015	7.18	1.53	50	7.74	1.93	50	8.1%	−0.32 [−0.71, 0.08]	2015
Moura, O 2015	15.25	5.67	50	15.86	5.77	50	8.2%	−0.11 [−0.50, 0.29]	2015
Booth 2013	6.57	2.06	21	6.38	1.2	21	6.5%	0.11 [−0.49, 0.72]	2013
Luo, Y 2013	3.5	1.24	15	3.4	0.83	15	0.0%	0.09 [−0.62, 0.81]	2013
Wang 2013	96.74	14	46	105.11	12.56	45	0.0%	−0.62 [−1.04, −0.20]	2013
Menghini2011	9.2	2.9	28	14.7	6.2	22	6.5%	−1.17 [−1.77, −0.56]	2011
Menghini 2011	9.7	2.4	26	15.7	5.5	24	6.4%	−1.41 [−2.04, −0.79]	2011
Attree2009	14.61	0.56	21	12.67	0.45	21	0.0%	3.75 [2.71, 4.78]	2009
Kibby2008	102.61	12.24	23	103.5	11.61	30	7.0%	−0.07 [−0.62, 0.47]	2008
Kibby 2008	94.78	11.43	23	96.83	11.63	30	7.0%	−0.17 [−0.72, 0.37]	2008
Marzocchi 2008	−16.5	1.34	22	−21.3	6.8	30	6.7%	0.90 [0.32, 1.48]	2008
Willcutt 2005	−46.2	19.6	109	−37.2	16.4	151	9.2%	−0.50 [−0.75, −0.25]	2005
Jeffries2004	4.05	0.67	21	4.25	0.74	40	7.1%	−0.28 [−0.81, 0.26]	2004
Jeffries 2004	4.14	1.39	21	4.35	1.27	40	7.1%	−0.16 [−0.69, 0.37]	2004
Swanson 2001	3.87	1.31	16	3.9	1.2	20	6.1%	−0.02 [−0.68, 0.63]	2001
Swanson1996	2.81	0.95	22	4.02	1.08	34	6.7%	−1.16 [−1.74, −0.58]	1996
Total (95% CI)			**456**			**592**	**100.0%**	**−0.33 [−0.60, −0.07]**	

Heterogeneity: $Tau^2 = 0.18$; $Chi^2 = 51.50$, df = 13 (P < 0.00001); $I^2 = 75\%$
Test for overall effect: Z = 2.51 (P = 0.01)

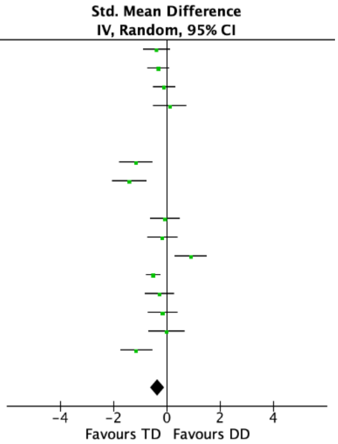

Figure 4. Random Effect model Forest Plot for Comparison between DD and TD Except for Chinese Speakers

From the Figure 5, heterogeneity was large ($I^2 = 75\%$), $Tau^2 = 0.18$, $p < 0.00001$, indicating unidentified sources of variability. There did not detect publication bias (see figure 5).

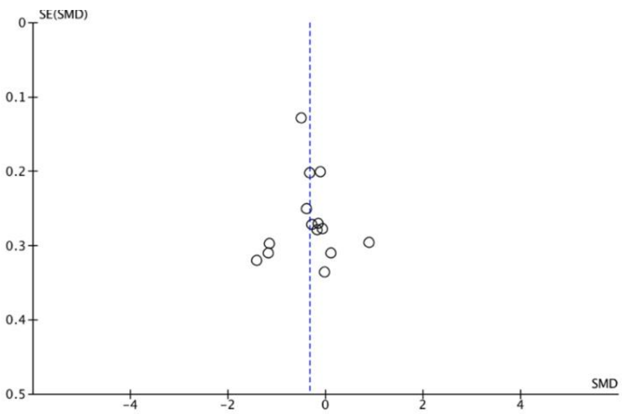

Figure 5. Publication Bias Funnel Plot for Comparison between DD and TD Except for Chinese Speakers

Discussion and Conclusion

To evaluate whether dyslexic children have impairments in VSWM capacity, a meta-analysis was conducted. As predicted, the significant effect size indicated that DD children performed worse in VSWM than healthy people. To assess the influences of different languages in VSWM, a subgroup analysis was applied. Both children whose L1 were alphabetic language and Chinese L1 children with dyslexia displayed a worse score in the VSWM tests.

The main finding in current studies is that dyslexic children have impairments in VSWM, which is inconsistent with the previous meta-analysis by Swanson (2009). This result indicates that dyslexic children also have impairments in VVSP, suggesting that DD might be a domain-general disorder. This possible explanation coincides with previous studies on the Chinese dyslexic population. Chinese is a logographic language, and Chinese experts proposed that the Chinese dyslexic population has impairment in PL, which has been studied in the western country, and in VSWM. In our research, there are two studies on Chinese dyslexic children. The subgroup analysis found the consistent result that Chinese dyslexic children have impairment in VSWM no matter the language.

However, the research by Attree in 2009 was found to be an outlier. The research used a virtual reality test, which is a different experimental method from traditional paradigms. Virtually reality (VR) test assesses children's spatial memory in a real-life situation with VR technology (Attree et al., 2009). As the authors argued, a possible explanation could be that the dyslexic population might perform better on tasks that simulate the real world. Subsequent studies also revealed no statistical difference in performance between dyslexic and healthy university students in VR VSWM tests (Kalyvioti & Mikropoulos, 2013). This effect from the VR technology could result from the enhancing presence, the multisensory approach and the positive attitude that the children experience was recorded while using VR. Hence, VR tests are more adaptable for children (Kalyvioti & Mikropoulos, n.d.). VR tests are easy to understand and perform, leading to more accurate data. Whether testing methods influence the performance of dyslexic children deserves further investigation.

In conclusion, our results demonstrated that compared with TD peers, dyslexic children have deficits in VSWM. However, whether language or task influences the results still needs further investigation. One limitation in our study is that we only researched in one database, and thus, the data we collected was not comprehensive. Regarding whether dyslexia children have impairments VSWM, we still need more evidence to offer a definite answer.

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Appendix 1. Characteristic form

First Author	Date	Lang Country	Mean Age(SD)	Groups Tested	Task
Alloway	2017	English	9.9(11.98)	DD&TD	Mr.X test
Moura, O	2015	Portugal	9.8 (1.38)	DD&TD	Mr. X test
Luo, Y	2013	Chinese	9.8 (1.08)	DD&TD	Corsi span task
Wang	2013	English	113.76 (7.8) (months)	DD&TD	spatial recall task
Booth	2013	English	10.7(0.42)	RD&TD	S-CPT
Menghini	2011	Italian(primary)	9.8(0.7)	RD&TD	Visual -spatial Span Task
Menghini	2011	Italian(middle)	12.4(0.9)	RD&TD	Visual -spatial Span Task
Attree	2009	English	13.4(0.717)	RD&TD	VE task
Marzocchi	2008	Italian	9.38(1.34)	NC&RD	SoP errors
Kibby	2008	English	9.81(2.59)	RD&TD	Dot Locations Learning and Faces
Willcutt	2005	English	11(2.4)	RD&TD	CANTAB
Jeffries	2004	English	129.6 (28.67) (months)	RD&TD	WM block recall span and WM mazes memory span
Swanson	2001	English	11.06(2.17)/11.49(1.97)	RD&TD	Visual Matrix
Swanson	1996	English	8.07(0.39)	RD&TD	Visual Matrix

Appendix 2. Data extracted from the Articles

Author	Year	Language	M Age	SD Age	Task	N(DD)	M(DD)	SD(DD)	Control Type	N(TD)	M(TD)	SD(TD)	Score	N	g	Var	J
Alloway	2017	English	9.9	11.98	Mr. X test	24	95.38	18.55	age	50	102.86	19.25	standard	74	-0.389028	0.06268925	0.98969072
Moura, O	2015	portuguese	9.8	1.38	Corsi Block Test	50	7.18	1.53	age	50	7.74	1.93	RAW	100	-0.3191155	0.04050917	0.99240506
Moura, O	2015	Portuguese	9.8	1.38	Rey Complex Figure Test	50	15.25	5.67	age	50	15.86	5.77	1.Central Executive(A):This task required that the child correctly recall a series of two to eight digits in the reverse order. One point per trial was given for correct recall	100	-0.1058294	0.040056	0.99240506
Booth	2013	English	10.7	0.42	S-CPT	21	6.57	2.06	age	21	6.38	1.2	standard	42	0.11063416	0.09538381	0.98159509
Luo, Y	2013	Chinese	10.2	1.08	Corsi span task	15	3.5	1.24	age	15	3.4	0.83	standard	30	0.0923047	0.13347534	0.97391304
Wang	2013	English	113.76	7.8	spatial recall task	46	96.74	14	age	45	105.11	12.56	standard	91	-0.6237089	0.04609879	0.99164345
Menghini	2011	Italian(primary)	9.8	0.7	Visual -spatial Span Task	28	9.2	2.9	age	22	14.7	6.2	raw	50	-1.166607	0.09477855	0.98461538
Menghini	2011	Italian(middle)	12.4	0.9	Visual -spatial Span Task	26	9.7	2.4	age	24	15.7	5.5	raw	50	-1.4124188	0.10007747	0.98461538
Attree	2009	English	13.4	0.717	VE test	21	14.61	0.56	age	21	12.67	0.45	standard	42	3.74871286	0.26253391	0.98159509
Kibby	2008	English(USA)	9.81	2.59	Dot locations learning	23	102.61	12.24	language	30	103.5	11.61	standard	53	-0.0737937	0.07686297	0.98550725
Kibby	2008	English(USA)	9.81	2.59	faces	23	94.78	11.43	language	30	96.83	11.63	standard	53	-0.1750055	0.07710053	0.98550725
Marzocchi	2008	Italian	9.38	1.34	Self Ordered Pointing Task	22	-16.5	1.34	language	30	-21.3	6.8	raw	52	0.90059683	0.08658667	0.98522167
Willcutt	2005	English	11	2.4	CANTAB	109	-46.2	19.6	language	151	-37.2	16.4	raw	260	-0.5038795	0.01628509	0.99710145
Jeffries	2004	English	129.6	28.67	WM block recall span	21	4.05	0.67	language	40	4.25	0.74	raw	61	-0.2754244	0.07324084	0.9874477
Jeffries	2004	English	129.6	28.67	WM mazes memory span	21	4.14	1.39	language	40	4.35	1.27	raw	61	-0.1580629	0.07282383	0.9874477
Swanson	2001	English	11.49/10.72	1.97/2.25	Visual Matrix	16	3.87	1.31	age	20	3.9	1.2	raw	76	-0.0350594	0.23750809	0.98996656
Swanson	1996	English	8.07	0.39	Visual Matrix	22	2.81	0.95	age	34	4.02	1.08	raw	56	-1.1570994	0.08682059	0.98630137

Appendix 3. Quality Appraisal [The quality of the studies is assessed according to these questions (Critical Appraisal Skills Programme, 2017)]

First Author (Year)	Relevance		Population				Measures			Results			Summary of Study	
	1	2	3	4	5	6	7	8	9	10	11	12	Limitations/Specificat	Overall Quality
Moura(2015)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	No CB test	High
Luo(2013)	Y	Y	N	Y	Y	Y	Y	Y	Y	N	Y	Y	small sample size; difference in the mean age reported and the result calculated from the form	High
Wang	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		high
Alloway	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		high
Booth	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		high
Marzocchi	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		high
Swanson(2001)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		high
Willcutt	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	large sample	high
Swanson(1996)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	negative : abbreviation confused	high
Menghini(2011)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	do not afford the data of SD age	high
Kibby(2008)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Unbalaenced number of sample	high
Jeffries(2004)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Unbalaenced number of sample	high
Attree(2009)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		high