Original Article

Transcranial direct current stimulation to enhance mathematical performance in school going developmental dyscalculic children: A single group pretest-posttest, quasi experimental study

Estimulação transcraniana por corrente contínua para melhorar o desempenho matemático em crianças discalculia de desenvolvimento em idade escolar: um único grupo pré-teste-pós-teste, estudo quase experimental

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ABSTRACT | INTRODUCTION: Developmental dyscalculia (DD) deals with impaired mathematical performance and affects children's educational and day-to-day activities. There is evidence that transcranial direct current stimulation (tDCS) applied to the posterior parietal cortex facilitates the hypoactive neuronal structure and improves mathematical performance in individuals with DD. **OBJECTIVE:** The objective of this study is to investigate whether tDCS adjuvant with conventional numeracy training (CNT) would enhance the mathematical abilities of school-going children affected with DD. **MATERIALS AND METHODS:** Thirteen school-going children affected with DD received tDCS and CNT three sessions per week for up to 2 consecutive weeks. Left anodal and right cathodal stimulation at P3/P4 region with 2mA intensity combined with CNT for 30 minutes in a day was given. Learning disability diagnostic inventory (LDDI) was used as an outcome measure and collected at baseline and the end of the 2-week intervention. **RESULTS:** There was a significant improvement in the mathematical performance of school-going children. The results show statistically as well as a clinically significant improvement after the two weeks of intervention. **CONCLUSIONS:** tDCS combined with CNT effectively improves the mathematical abilities of school-going children affected with DD. The findings of this study provide a new perspective for the rehabilitation of school-going DD children.

KEYWORDS: Children. Dyscalculia. Transcranial Direct Current Stimulation. Rehabilitation.

RESUMO | INTRODUÇÃO: A discalculia do desenvolvimento (DD) lida com o desempenho matemático prejudicado e afeta as atividades educacionais e do dia a dia das crianças. Há evidências de que a estimulação transcraniana por corrente contínua (ETCC) aplicada ao córtex parietal posterior facilita a estrutura neuronal hipoativa e melhora o desempenho matemático em indivíduos com DD. **OBJETIVO:** O objetivo deste estudo é investigar se tDCS adjuvante com treinamento convencional de numeramento (CNT) aumentaria as habilidades matemáticas de crianças em idade escolar afetadas com DD. **MATERIAIS E MÉTODOS:** Treze crianças em idade escolar afetadas com DD receberam tDCS e CNT três sessões por semana por até 2 semanas. Foi dada estimulação anódica esquerda e catódica direita na região P3 / P4, com intensidade de 2mA, combinada com CNT por 30 minutos em um dia. O inventário de diagnóstico de deficiência de aprendizagem (LDDI) foi usado como uma medida de resultado e coletado no início e no final da intervenção de 2 semanas. **RESULTADOS:** Houve melhora significativa no desempenho matemático de crianças em idade escolar. Os resultados mostram uma melhora estatística e clinicamente significativa após 2 semanas de intervenção. **CONCLUSÕES:** tDCS combinado com CNT é eficaz para melhorar as habilidades matemáticas de crianças em idade escolar afetadas com DD. Os resultados deste estudo fornecem uma nova perspectiva para a reabilitação de crianças com DD em idade escolar.

PALAVRAS-CHAVE: Crianças. Discalculia. Estimulação Transcraniana por Corrente Contínua. Reabilitação.

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Introduction

Developmental dyscalculia (DD) is a persistent difficulty in learning mathematical operation, recognition, and manipulation, which occurs in 07% of children globally and 10.5% of children in Indian scenario.[1,2] DD is defined as a disorder of mathematical abilities that occurs due to deficient development of the frontoparietal network and leads to impaired quantity description, counting skills, mental calculation ability, and symbolic number representations.[3] According to the World Health Organization (WHO) and diagnostic statistic manual 5th revision of APA, DD is a domain-specific learning disorder that emerges at an early stage of development and can be described as inappropriate schooling or deficient learning opportunities.[4] Distributed neural systems in the bilateral hemisphere are involved in a mathematical function. Number representation and processing occur in the parietal lobe, whereas the intraparietal sulcus (IPS) is confirmed as the processing of numerical problems.[5] However, other brain regions are also associated mainly with the prefrontal cortex associated with numerical cognition, planning, and manipulating information required in calculation tasks. Therefore, number processing, numerical tasks, and calculation are processed by combining the parietal lobe, prefrontal cortex, cerebellum, dorsal and ventral visual pathway, and subcortical areas. Study shows that in DD there is abnormal parietal activity and hypoactivation in other brain regions such as frontal lobe, occipital areas, and deep brain structures.[6]

To date, only neuropsychological methods that include interdisciplinary approaches such as neuroscience, psychology, and education have been adopted to remediate DD, supporting that these interventions improve the activity of different brain regions.[7] However, direct activation of brain structures could lead to positive effects. The use of non-invasive brain stimulation offers different brain regions' facilitation by inducing excitability and may result in activation and improved functions.[8]Applications of transcranial direct current stimulation (tDCS) to rehabilitative purpose in DD are reported and documented improved numerical proficiency after anodal stimulation at the left posterior parietal cortex in adults with dyscalculia.[9,10] However, to date, no study has been conducted yet to establishes the efficacy of tDCS in improving the mathematical abilities of school-going children affected with DD.

The null hypothesis is that there is no significant impact on the mathematical performance of DD children after the application of tDCS. The alternate hypothesis is that there is a significant impact on the mathematical performance of DD children after the application of tDCS. Therefore, the present single group study is aimed at evaluating the effectiveness and long-lasting effects of left anodal (P3) right cathodal (P4) tDCS at the parietal-temporal region in the mathematical performance of DD.

Specifically, in individuals with DD, a reduced activity at IPS and increasing the superior and inferior parietal cortex of the right hemisphere has been found during functional magnetic resonance imaging (fMRI) study.[11] Similarly, in normal individuals, the study showed that increase activity in IPS and decreased activity in the superior and inferior parietal cortex are associated with higher mathematical performance. Therefore, in the present study, tDCS was combined with conventional numeracy training to improve mathematical skills.

Materials and methods

This single-group pretest-posttest quasi-experimental study included 13 school-going children with DD recruited from recognized special schools for children. The diagnosis of DD was based on the DSM-5 criteria (American Psychiatric Association, 2013) and was made with a learning disability diagnostic inventory (LDDI). Participants were diagnosed with DD as per clinicians and neuropsychologists included in the study. All participants were able to understand the verbal commands, had normal vision and were right-handed. Inclusion criteria were right-handed children, age group 8 to 17 years, girls and boys (both gender), and school-going children diagnosed with developmental dyscalculia as per LDDI. Exclusion criteria were seizures, alcohol or drug abuse, central nervous system infection, any recent trauma or surgery, any metallic implant near electrode placement site, and cerebrovascular malformations. Written informed consent was obtained from all participant's teachers/parents, and informed assents from the children after explaining the procedure. Ethical clearance was obtained from the institutional research ethics committee of the recognized University (IEC/MMU/2018/118). This feasibility pilot trial was a part of a large study and registered under the Clinical trials registry of India on CTRI/2018/07/014834 on 12 July 2018 (updated on 26, April 2019). This study was performed following the world medical association declaration of Helsinki revised,2013, and the ethical guidelines adopted by the council for international organizations of medical sciences (CIOMS), the international ethical guidelines for health-related research involving humans (revised, 2016). This study also followed the national ethical guidelines for biomedical and health research involving human participants by the Indian Council of Medical Research, 2017. The study was conducted in the classroom of Vatsalya school for special children, Ambala Cantt, Haryana, India.

In the present single-group study, all participants were received left anodal (P3) and right cathodal (P4) tDCS at the parietal-temporal region combined with conventional numeracy training. In addition, 15 children aged between 8 and 17 years were assessed for eligibility to the study. Each participant was exposed to 30 minutes session of treatment received 3 sessions per week for 2 consecutive weeks with a minimum 24-hour interval between sessions. Outcome measures were assessed at baseline and the end of 2 weeks of treatment. LDDI was used to assess the mathematical performance of children and diagnose DD. The same evaluator applied the LDDI before and after the 2 weeks of intervention.

Procedures

Transcranial direct current stimulation (tDCS)

Direct current was generated by tDCS (MIND-ACQUITY, Transcranial DC power, MA-tDCS manufactured by Walnut Medical), an electric current was delivered to the head via a pair of the sponge-soaked electrode. Anodal electrode (25cm2) was positioned over the left parietal-temporal region according to the 10-20 EEG system corresponding at P3, whereas cathodal electrode (25cm2) was positioned on the right side of the parietal lobe corresponding to P4(Figure 1). The current intensity was increased slowly from 0.1 mA to 2 mA, and at the end of stimulation, the current was decreased slowly to 0 mA—the current intensity of 2 mA delivered for 30 minutes.

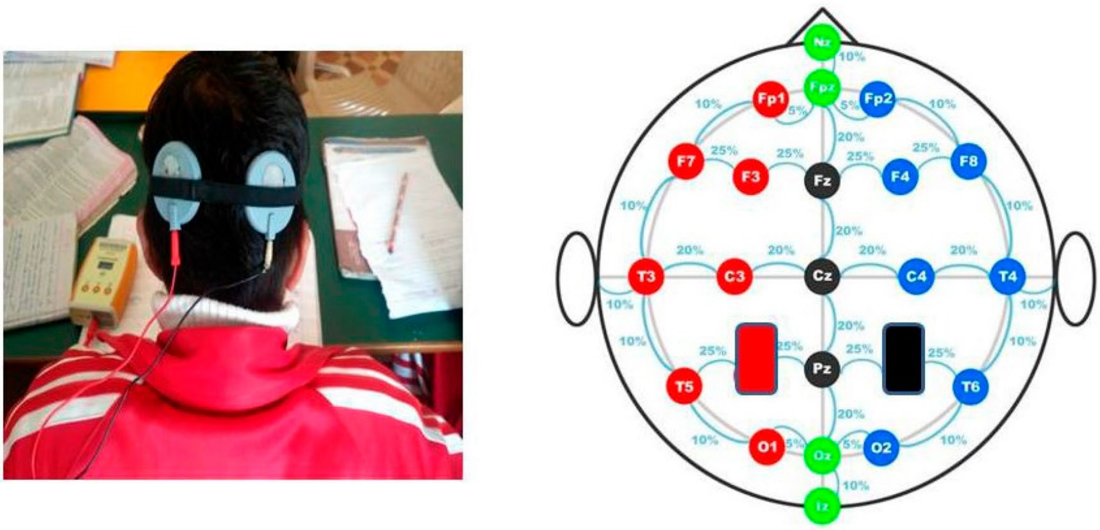
Conventional numeracy training

During tDCS, the participants underwent conventional numeracy training (CNT) for 30 minutes in all sessions. CNT consisted of six domains forward counting, backward counting, identification of numbers, breakdown numeracy, counting objects, and simple calculations. The details of the treatment protocol are listed in Table 1.

Table 1. Details of treatment protocol

Conventional Numeracy training	Intensity of training
1. Forward number counting (It includes counting from 01 to 50)	1. 5 reps 1 sets/day X 3 days/week, for 2 weeks
2. Backward counting (It includes counting from 100)	2. 5 reps 1 sets/day X 3 days/week, for 2 weeks
3. Identification of numbers (Identification of simple numbers and complex numbers)	3. 5 reps 1 sets/day X 3 days/week, for 2 weeks
4. Break numeracy down into tens elements	4. 5 reps 1 sets/day X 3 days/week, for 2 weeks
5. Counting Objects	5. 5 reps 1 sets/day X 3 days/week, for 2 weeks
6. Simple two to three digit calculations (It includes addition, subtraction, multiplication and division)	**6.** 5 reps 1 sets/day X 3 days/week, for 2 weeks
Noninvasive brain stimulation	
1. Transcranial direct current stimulation (tDCS)	1. Left anodal/Right cathodal at P3/P4, 02 mA, 30 minutes/day X 3days/week, for 2 weeks

Figure 1. Representation of electrode placement site



Data Analysis

Data were analyzed using IBM SPSS statistics software version 20.0. The normality of the data was analyzed with the Shapiro-Wilk test as the sample size was less than 50. The data followed a normal distribution, and variables were presented in mean and 95% confidence intervals. Paired t-test was used to analyze the statistical significance. A P-value of ≤0.05 was considered statistically significant. The effect size was calculated to analyze the clinical significance and interpretation is to refer to effect sizes as small (d = 0.2), medium (d = 0.5), and large (d = 0.8) based on benchmarks suggested by Cohen. Posthoc analyses were performed to determine the type-2 error. Due to the lack of an a priori sample size calculation, the study's power was calculated using G* Power 3.1.9.4 software.

Results

The demographic and baseline characteristics of all participants are displayed in Table 2.

15 participants were included in this study. Among them, 13 children were eligible for enrolment (2 children were excluded due to not meeting inclusion criteria). Baseline and at the end of 2-week intervention changes on outcome measures (expressed in Mean and 95% confidence interval), effect size (Cohen's d effect size), and power of the study are displayed in Table 3. The power of the study proves that the study is sufficiently powered (100%) for outcome measure (LDDI). Furthermore, significant improvement ($p \leq 0.05$) is observed in LDDI outcomes and confirms that interventions might effectively improve the mathematical performance of DD children.
The detailed study description showed in Figure 2.

Figure 2. Flow chart of the study

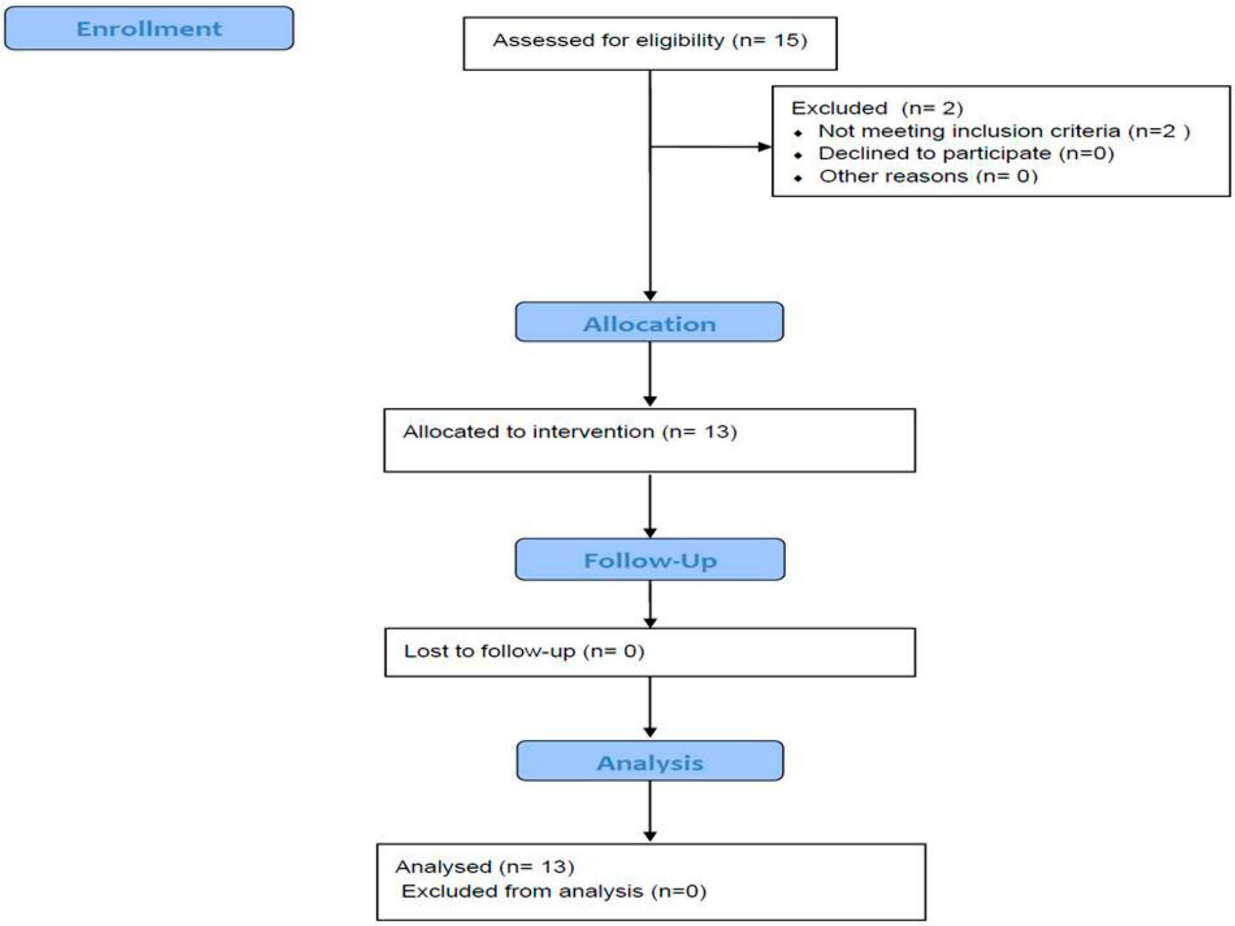


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Table 2. Demographic and baseline characteristics of all the participants

Participant	Age (in Years)	Gender	LDDI (Baseline)
1	15	M	33
2	13	M	24
3	12	M	21
4	15	M	27
5	16	F	32
6	12	M	20
7	15	F	25
8	14	M	24
9	14	M	38
10	14	F	33
11	13	M	39
12	16	F	40
13	11	F	34

M= Male, F=Female, LDDI= Learning disability diagnostic inventory

Table 3. Comparison of outcome measures between baseline and at end of 2-week intervention, effect size and Power analysis

Outcome measure	Baseline score (Mean, 95% CI)	At end of 2 week (Mean, 95% CI)	p-value	Effect size	Power analysis
LDDI	30 (25.8-34.1)	70.4 (66.6-74.2)	0.00	5.7	1.00

CI= Confidence Interval, LDDI= Learning disability diagnostic inventory

Discussion

Noninvasive brain stimulation such as tDCS is an emerging method for treating patients suffering from neurological and neuropsychological disorders.[12,13] In the area of learning disability, several studies have investigated the beneficial effect of tDCS on reading and various components of mathematical problems such as problem-solving and learning.[14,15] Many imaging studies are also demonstrated neural activity and processing during tDCS stimulation.[16] To the best of our knowledge, the present study is the first study to use tDCS simultaneously, conventional numerical training (CNT) in school-going DD children. Our results support the hypothesis that tDCS combined with CNT enhance the mathematical performance of school-going DD children. This study follows a previously published study, reporting active tDCS applied at the left parietal cortex improves arithmetic learning and performance and proved using simultaneous functional magnetic resonance imaging (fMRI) study.[17] tDCS applied to left P3 facilitates the activity of IPS and parietal cortex. The relationship between the left parietal lobe and mathematical performance is also supported by neuro-cognitive data deriving from dyscalculia.[18]

In the present study, we combined tDCS with CNT to determine the concurrent application of brain-cognitive rehabilitation approaches in DD. The present study provided sufficient evidence that the combination of active tDCS with CNT significantly improves the mathematical performance of DD children. The CNT was used to improve mathematical performance. In the previous study, numeracy intervention was provided to the DD children to improve basic numerical knowledge and conceptual knowledge and reported positive intervention effects.[18] In this study, we used a specially designed CNT protocol to improve the mathematical performance of DD children. The previous study results documented only preliminary evidence on a small number of participants (n=6). Hence, we have recruited more participants (n=13) for this study to provide CNT. The present quasi-experimental study provides the first evidence of enhancing mathematical performance in school-going DD children by combining tDCS and CNT. The major limitation of the study was the small sample size and lack of comparative agents. Our results may become a setting parameter that might be used in structured rehabilitation strategies. Present findings need to be further explored in larger clinical trials to establish the potential benefits of tDCS for the treatment of DD.

Conclusion

tDCS adjuvant with CNT might help in improving mathematical performance in school-going DD children. Clinical and statistically significant improvements were observed after 2 weeks of intervention. Therefore, this protocol can be incorporated with other therapies to improve mathematical performance.

Author contributions

Srivastav AK and Chatterjee SC participated in the study design, data acquisition, data analysis and/or interpretation, manuscript writing, critical review of intellectual content, and final approval of the article.

Competing interests

No financial, legal or political competing interests with third parties (government, commercial, private foundation, etc.) were disclosed for any aspect of the submitted work (including but not limited to grants, data monitoring board, study design, manuscript preparation, statistical analysis, etc.).

References

1. Mogasale VV, Patil VD, Patil NM, Mogasale V. Prevalence of specific learning disabilities among primary school children in a south Indian city. Indian J Pediatr. 2012;79(3):342–7. https://doi.org/10.1007/s12098-011-0553-3

2. Shalev RS, von Aster MG. Identifcation, classification, and prevalence of development dyscalculia. Encyclopedia of Language and Literacy Development [Internet]. Available from: https://www.zora.uzh.ch/id/eprint/12874/1/Shalev_Identification_V.pdf. [Epub ahead of print]

3. Kucian K, von Aster M. Developmental dyscalculia. Eur J Pediatr. 2015;174(1):1–13. https://doi.org/10.1007/s00431-014-2455-7

4. American Psychiatric Association. Diagnostic and statistical manual of mental disorders: DSM-5TM. 5th ed. Arlington, VA, US: American Psychiatric Publishing; 2013.

5. Butterworth B, Walsh V. Neural basis of mathematical cognition. Curr Biol. 2011;21(16):R618–21. http://dx.doi.org/10.1016/j.cub.2011.07.005

6. Kaufmann L, Vogel SE, Starke M, Kremser C, Schocke M, Wood G. Developmental dyscalculia: Compensatory mechanisms in left intraparietal regions in response to nonsymbolic magnitudes. Behav Brain Funct. 2009;5:35. https://doi.org/10.1186/1744-9081-5-35

7. Butterworth B, Laurillard D. Low numeracy and dyscalculia: Identification and intervention. ZDM - Int J Math Educ. 2010;42(6):527–39. https://doi.org/10.1007/s11858-010-0267-4

8. Bolognini N, Pascual-Leone A, Fregni F. Using non-invasive brain stimulation to augment motor training-induced plasticity. J Neuroeng Rehabil. 2009;6:8. https://doi.org/10.1186/1743-0003-6-8

9. Iuculano T, Kadosh RC. Preliminary evidence for performance enhancement following parietal lobe stimulation in Developmental Dyscalculia. Front Hum Neurosci. 2014;8:38. https://doi.org/10.3389/fnhum.2014.00038

10. Hauser TU, Rotzer S, Grabner RH, Mérillat S, Jäncke L. Enhancing performance in numerical magnitude processing and mental arithmetic using transcranial Direct Current Stimulation (tDCS). Front Hum Neurosci. 2013;7:244. https://doi.org/10.3389/fnhum.2013.00244

11. Rivera SM, Reiss AL, Eckert MA, Menon V. Developmental changes in mental arithmetic: Evidence for increased functional specialization in the left inferior parietal cortex. Cereb Cortex. 2005;15(11):1779–90. https://doi.org/10.1093/cercor/bhi055

12. Schulz R, Gerloff C, Hummel FC. Non-invasive brain stimulation in neurological diseases. Neuropharmacology. 2013;64:579–87. http://dx.doi.org/10.1016/j.neuropharm.2012.05.016

13. Kuo MF, Paulus W, Nitsche MA. Therapeutic effects of non-invasive brain stimulation with direct currents (tDCS) in neuropsychiatric diseases. Neuroimage. 2014;85:948–60. http://dx.doi.org/10.1016/j.neuroimage.2013.05.117

14. Kadosh RC, Dowker A, Heine A, Kaufmann L, Kucian K. Interventions for improving numerical abilities: Present and future. Trends Neurosci Edu. 2013;2(2):85–93. http://dx.doi.org/10.1016/j.tine.2013.04.001

15. Costanzo F, Varuzza C, Rossi S, Sdoia S, Varvara P, Oliveri M, et al. Evidence for reading improvement following tDCS treatment in children and adolescents with Dyslexia. Restor Neurol Neurosci. 2016;34(2):215–26. https://doi.org/10.3233/rnn-150561

16. Rudroff T, Workman CD, Fietsam AC, Ponto LLB. Imaging Transcranial Direct Current Stimulation (tDCS) with Positron Emission Tomography (PET). Brain Sci. 2020;10(4):236. https://doi.org/10.3390/brainsci10040236

17. Hauser TU, Rütsche B, Wurmitzer K, Brem S, Ruff CC, Grabner RH. Neurocognitive Effects of Transcranial Direct Current Stimulation in Arithmetic Learning and Performance: A Simultaneous tDCS-fMRI Study. Brain Stimul. 2016;9(6):850–8. http://dx.doi.org/10.1016/j.brs.2016.07.007

18. Price GR, Holloway I, Räsänen P, Vesterinen M, Ansari D. Impaired parietal magnitude processing in developmental dyscalculia. Curr Biol. 2007;17(24):R1042-3. https://doi.org/10.1016/j.cub.2007.10.013