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The use of the Bilingual Aphasia Test for assessment and transcranial direct current stimulation to modulate language acquisition in minimally verbal children with autism

HARRY D. SCHNEIDER[1,2] & JENNA P. HOPP[2]

[1]*Program for Cognitive Sciences, Columbia University Medical Center, New York, NY, USA,* [2]*The Center for Medical and Brain Sciences, Plainview, NY, USA*

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Abstract
Minimally verbal children with autism commonly demonstrate language dysfunction, including immature syntax acquisition. We hypothesised that transcranial direct current stimulation (tDCS) should facilitate language acquisition in a cohort ($n = 10$) of children with immature syntax. We modified the English version of the Bilingual Aphasia Test (BAT) to test only basic canonical subject–verb–object sentences. We tested syntactic accuracy after teaching then testing all vocabulary from the subsequent syntax test to ensure validity of syntactic scoring. We used scaffolding sentences for syntax training. All procedures were performed both before and after tDCS. Results demonstrated a large effect size of the difference between pre-/post-tDCS groups ($p < 0.0005$, $d = 2.78$), indicating syntax acquisition. Combining a modified BAT with tDCS constitutes effective modalities for assessment and treatment of immature syntax in children with autism. Future studies should explore the BAT for patients with an inability to use or understand language, in particular bilingual children with autism.

Keywords: *syntax, first language acquisition, neuromodulation, multilingual, bilingual children with autism, modified Bilingual Aphasia Test*

Introduction

It is said that when a dog bites a man, that is not news, but when a man bites a dog, that is news. In this simple, canonical subject–verb–object (SVO) sentence, the order of the nouns placed in the subject and object positions were reversed, rendering it newsworthy. Rules of word order are referred to as syntax, which consists of the principles for constructing sentences to properly convey intention and which may impart meaning.

When the use of syntax becomes automatic, unconscious and systematic it is compatible with what Paradis (2004) calls 'linguistic competence', which is *implicit* and is referred to as knowing *how*. There is a neural procedural memory network, which subserves linguistic

Correspondence: Harry D. Schneider, Program for Cognitive Sciences (P.I.C.S.), Columbia University Medical Center, 710 West 168th Street Suite B-41 Box 108, New York, NY 10032, USA. E-mail: hds7@columbia.edu

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competence. Appropriation of the lexicon is *explicit*, consciously learned, referred to as knowing *that* (Paradis, 2004) and is subserved by a neural *declarative* memory network. These two neural networks underlie implicit and explicit memory (Ullman, 2004).

The network for procedural memory underlies unconscious motor and cognitive skills, including the rules of grammar. The network for declarative memory subserves conscious recall of data as evidenced in semantic and episodic memories. Ullman's descriptions of the cerebral representation of the language system, including phonology, morphology, syntax and semantics, refer to areas most often found in the left hemisphere of the brain such as the prefrontal and temporal cortices, whereas pragmatics is subserved by areas in the right hemisphere (Paradis, 1998). The left prefrontal cortex contains Broca's area for speech production as well as the dorsolateral prefrontal cortex (DLPFC), an executive control area of the brain. The left temporal cortex contains the putative Wernicke's area for speech comprehension. The left temporal and prefrontal cortices are collectively called the perisylvian area.

The prefrontal cortex, specifically Broca's area, is richly interconnected with the basal ganglia (BG), sub-cortical structures that project back to the left prefrontal cortex. These connections are called corticostriatal ('striatal' refers to BG) pathways and almost every part of the cortex connects to the BG. These corticostriatal pathways are intimately connected to procedural learning and memory of skills, such as playing the piano by ear or learning to speak one's native language. In a first language these pathways are important in the acquisition of grammar. They are also necessary for sequence learning (Sakai, Hirosaka, Miyauchi, Takino, Sasaki, and Putz, 1998), storage and the retrieval of procedural memories. They are also involved in motivation and automatisation of rules and unconscious motor planning. The execution of well-learned motor actions (fluent speech production) does *not* require higher-level cognitive functioning (Schumann, Crowell, Jones, Lee, and Schuchert, 2004). Grammar refers to the rules of language. These 'rules' are most likely represented in the BG as parallel-distributed processing mechanisms or as mathematical probability connections (Paradis, 2004). They are exceedingly complex neuronal circuits whose behavioural output we interpret as the rules of language (Newman, Supalla, Hauser, Newport, and Bavelier, 2010).

Mapping the neural substrates of language in children with autism may provide insight into their language deficits. Neuroimaging studies have demonstrated both dysfunctional brain areas and aberrant connectivity patterns in patients with autism (Palmen, van Engeland, Hof, and Schmitz, 2004). The structural anatomy of the BG is deformed and the cortical areas to which their axons project are pathologically distributed (Crosson, Benefield, Cato, Sadek, Bacon Moore, Wierenga, Gopinath, Soltysik, Bauer, Auberbach, Gökçay, Leonard, and Briggs, 2003). These studies suggest that during the period of first language acquisition, neurotypical corticostriatal pathways used for grammar acquisition became dysfunctional and inhibited normative implicit language acquisition, resulting in an immature syntax foundation (Foudon, Reboul, and Manificat, 2008).

The core features of classical autism include difficulty with social interaction, stereotypical behaviours, stereotyped motor movements, such as hand flapping, and deficits in language function and communication (American Psychiatric Association, 2000). Language deficits usually appear by 18 months of age and affect phonology, morphology, syntax, semantics and pragmatics (Tager-Flusberg, 1981). For example, children with autism do not make use of phonemic classes and they reveal an irregular frequency distribution of types of phonological errors (substitution, deletion, assimilation and addition). Their use of suprasegmental features, such as stress and intonation, often result in monotonal or inappropriate intonation.

These children demonstrate pronoun reversals. They have a difficulty with abstract words (e.g. 'from' has no meaning to children with autism) and they often use scripted, unrelated responses to questions (when asked 'what do you want to eat?' they may respond with 'the wonderful world of Disney'). Most children with autism have not acquired the implicit linguistic competence needed to automatically, fluently and consistently generate correct markers of morphosyntax (Tager-Flusberg, 1981). Syntactically there is often an absence of grammatical morphemes, for example, articles, copula, auxiliaries, pronouns and prepositions. Children with autism and their typically developing (TD) peers often use a word-order strategy for developing syntax; for example, noun–verb–noun is often interpreted as agent–action–object (Volkmar, Cohen, Paul, and Klin, 2005). To some degree, language-acquisition impairments may also result from a greater propensity in children with autism to use explicit strategies rather than to rely on implicit ones (Dawson, Mottron, and Gernsbacher, 2008).

The prevalence of autism has increased from 40 years ago when the rate was estimated at 30–60 per 10,000 (Rutter, 2005) to a prevalence of 60–70 per 10,000. It is estimated that approximately 1 in 150 children is affected (Fombonne, Quirke, and Hagen, 2009). Many biological and environmental explanations have been suggested, but have been inconclusive in isolating the exact cause of this upsurge. Fombonne et al. (2009) postulate that the increased prevalence may be partially attributed to changes in diagnostic criteria, diagnostic substitutions, changes in the policies for special education, increased availability of services and referral patterns and heightened public awareness. The validity of current epidemiological data needs further elucidation.

Language abnormalities are often the first symptoms of autism alerting parents to a possible communication delay (Howlin, 1981). Parents seek professional healthcare providers such as paediatricians, neurologists, psychiatrists and speech-language pathologists, who often provide an initial diagnostic evaluation of autism. Subsequent diagnostic testing such as the Autism Diagnostic Observation Schedule-Generic and the Autism Diagnostic Interview – Revised (Filipek, Accardo, Baranek, Cook, Dawson, Gordon, Gravel, Johnson, Level, Minshew, Prizant, Rapin, Rogers, Stone, Teplin, Tuchman, and Volkmar, 1999) employs standardised behavioural evaluations. Currently, experimental neuroimaging techniques such as functional magnetic resonance imaging, diffusion tensor imaging, single-photon emission computed tomography and positron electron tomography are being used to help evaluate language dysfunction (Filipek, Accardo, Ashwal, Baranek, Cook, Dawson, Gordon, Gravel, Johnson, Kallen, Levy, Minshew, Ozonoff, Prizant, Rapin, Rogers, Stone, Teplin, Tuchman, and Volkmar, 2000). They are often used to provide additional information to substantiate standardised behavioural testing. Regardless of test results, parents continue to seek effective treatment modalities to restore functional language (Giacomo, 1998).

There are different types of language treatments offered for autism. Treatment methods including behavioural interventions, traditional pharmacotherapy and complementary/alternative therapies have not shown significant success in increasing functional language (Spence and Thurm, 2010). Research has demonstrated the success of neuromodulation techniques as a new treatment modality for general cognitive dysfunction (Nitsche, Schauenburg, Lang, Liebetanz, Exner, and Paulus, 2003c) and has also shown success in the facilitation of language acquisition for children with autism (Ilyukhina, Kozhushko, Matveev, Ponomareva, Chernysheva, and Shaptilei, 2005). Neuromodulation has demonstrated an increase in general sound and speech production in children aged 3–6 years with developmental retardation without noticeable side-effects (Kozhushklo, Sahitor, Ponomareva, and Berezhnia, 2007).

Since 2008, at Columbia University Medical Center, Program for Imaging and Cognitive Sciences, and The Center for Medical and Brain Sciences (CMBS), we have been clinically assessing and treating children with autism using transcranial direct current stimulation (tDCS), a non-invasive neuromodulation technique, to modulate different features of language. In addition to traditional explicit language therapy (conscious learning), we use implicit (unconscious) learning strategies to facilitate the acquisition of the rules of language vis-à-vis comprehensible input. Our techniques include affective humanistic activities in an attempt to activate imagination, problem-solving activities and interactive games (Krashen and Terrel, 1983).

An overview of our population's language deficits, specifically those patients whose syntax was immature, demonstrated a need to formalise an appropriate protocol to assess and treat these deficits in syntax. We conducted continual informal preliminary investigations to examine the strengths and weaknesses of our existing methodology to ascertain an effective platform for combining evaluations with treatments. For this research study on minimally verbal children with autism, we elected to evaluate syntax acquisition using a modified version of the syntax comprehension portion of the English version of the Bilingual Aphasia Test (BAT) because it isolates syntax from semantics. The BAT is a comprehensive language test originally designed to test differential language loss according to the structural and cultural references of each respective language of bilingual individuals with aphasia. The BAT assesses various linguistic skills, such as comprehension, repetition, judgement, lexical access, propositionising, reading and writing for each level of language, isolating phonology, morphology, syntax, lexicon and semantics (Fabbro, 2001). The syntax comprehension portion of the BAT presents various levels of syntactic constructions: standard sentences, two types of non-standard sentences, negative sentences, pronominal references to entities or to oneself and interrogative sentences (Paradis, 2004).

Subsequent to our preliminary investigations, initial testing with the BAT confirmed that none of the participants in this study were able to comprehend any of the syntax levels presented. The standard BAT begins with basic, canonical SVO sentences scores, which are compared to the scores for higher levels of syntactic sentences (Paradis and Libben, 1987). We modified the standard BAT by using first-level syntax constructions to create five additional first-level stimulus sentences, which served as our entire syntax comprehension test. Our study used basic standard canonical SVO sentences (e.g. *the girl holds the boy*) to test language acquisition before and after the use of tDCS.

tDCS increases neural plasticity (Nitsche, Doemkes, Karaköse, Antal, Liebetanz, Lang, Tergau, and Paulus, 2007) and creates electromagnetic fields that both stimulate and inhibit neurons in the brain (Nitsche and Paulus, 2000; Miranda, Lomarev, and Hallett, 2006). Low-level direct current is applied to the scalp and the current density produced is exceedingly small (Nitsche et al. 2003c). Safety criteria for the maximum amount of direct current have been established (28.57 mA/cm^2) (Nitsche, Liebetanz, Antal, Lang, Tergau, and Paulus, 2003a; Nitsche, Liebetanz, Lang, Antal, Tergau, and Paulus, 2003b; Nitsche et al., 2007; Wagner, Fregni, Fecteau, Grodzinsky, Zahn, and Pascual-Leone, 2007) and researchers have consistently reported success with current densities up to a 1000-fold lower (Poreisz, Boros, Antal, and Paulus, 2007). tDCS has been used extensively for cognitive and language treatments (Kincses, Antal, Nitsche, Bartfai, and Paulus, 2004) and has been shown to be a viable and safe treatment method for many conditions (Paulus, 2003, 2004) such as short-term memory loss (Marshall, Molle, Hallschmid, and Born, 2004; Vines, Schnider, and Schlaug, 2006), language recovery from post-stroke aphasia (Lang, Siebner, Ward, Lee, Nitsche, Paulus, Rothwell, Lemon, and Frackowiak, 2005; Hummel and Cohen, 2006) and other language-acquisition difficulties (Fregni, Boggio, Nitsche, Bermpohl, Antal, Feredoes, Marcolin, Rigonatti, Silva, Paulus, and Pascual-Leone, 2005).

During the prelinguistic communication period, TD children demonstrate increasing abilities in conveying meaning to interactive partners using intentional communication behaviours that are thought to be predictive of language functioning (Wilcox, 1993). The actual behaviours (vocalisations, gestures) should have function or meaning (requests, comments, protests, joint attention) that a child intends to convey (McDuffie, Yoder, and Stone, 2005). An investigation of 58 predominantly prelinguistic children with developmental disabilities also supported the notion of intentional communication being predictive of better language outcomes (McCathren, Yoder, and Warren, 1999).

A rationale for this study was to see whether tDCS would bring about syntax acquisition in children with autism who had not yet acquired basic syntax irrespective of previous intensive speech therapies. We had not witnessed novel verbal utterances; rather we heard the use of explicitly memorised phrases and simple repetitions of basic sentences, indications of not having acquired syntax. Children with autism are often trained to respond to questions (*what is this*?) with scripted answers (*this is a book*), but are not able to generalise the notion of word order to novel sentences. We noted that children had reading comprehension difficulties at an entry level of academic complexity consistent with immature syntax.

Methods

Participants

Individuals from the CMBS were considered for the study. They were diagnosed with classical autism by the principal investigator using the Autism Diagnostic Interview – Revised and scored less than 50 words (responses to questions or intelligible spontaneous utterances). Inclusion criteria were children that were native speakers of American English and deemed right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971). Participants attained specific prelinguistic behaviours thought to be requisite criteria for our test of syntax acquisition. These behaviours included intentional communication, demonstrated by attention following, initiating joint attention, behaviour self-regulation (Prizant and Wetherby, 1987) and good motor imitation. Other prelinguistic behaviours, such as situational awareness, eye contact, the use of one or more words (or approximations to a word) with meaning and showing an understanding of simple commands, either with or without vocal or physical cues (McDuffie et al., 2005) had been achieved. Participants demonstrated the ability to perform sequenced learning of unlearned scripted routines (i.e. those that were never seen before), which are known to increase the probability of language comprehension, a function of syntax acquisition (Kasari, Sigman, Mundy, and Yirmiya, 1990; Mundy, 1995; Mundy and Willoughby, 1998). Exclusion criteria were known seizure activity and any psychiatric or neurological disorder thought to interfere with the task. We then randomly selected 10 participants who met these criteria, 8 boys and 2 girls, corresponding to studies that suggest that autism is more prevalent among boys with a ratio of approximately 4:1 (Fombonne et al., 2009). Participants were aged 6–21 years (mean 9.8, SD 4.4). We obtained consent from a parent for each child.

Procedure

We present an overview of the tasks. We first taught the vocabulary that appeared in the syntax test and then we tested the participants to verify that they had learned these words. The vocabulary teaching was done to ensure that errors in the subsequent syntax section were due to a lack of linguistic understanding and not from a lack of understanding of the words used on the syntax test (Paradis, 2004). The vocabulary testing was followed by exposure to scaffolding sentences approximating the syntax to be tested; we then administered the syntax comprehension test. This entire procedure was performed both before and then after brain stimulation (tDCS). A maximum of 10 minutes was allotted to complete the procedure (2.5 minutes per section).

We used toys to simplify word appropriation. For the five target stimulus sentences (e.g. *the girl holds the boy*), five different pairs of toys ($n = 10$) were displayed to represent these nouns. We repeatedly labelled each toy while the child played with them. For vocabulary testing, we instructed the child to touch each stimulus toy upon request (e.g. 'touch the boy'). Post-tDCS only those participants achieving a score of over 80% on the vocabulary test progressed to the subsequent syntax comprehension section. For the syntax comprehension sentences, we selected appropriate verbs known to be familiar to these children. The verbs used were not explicitly taught; rather the principal investigator or research assistant demonstrated toys performing actions. For syntax training, we instructed the participants to touch the correct pictures of the toys representing scaffolding sentences. For example, we told participants to touch the pictures showing: 'the girl', 'the boy' and 'the boy and the girl'. Syntax training was continued until the participants identified all the pictures correctly. For the syntax comprehension test, we read a stimulus sentence (e.g. *the boy holds the girl*) and instructed the participants to touch the picture depicting that sentence. For the post-tDCS syntax comprehension test, each subsequent stimulus sentence was presented with the subject and object reversed (e.g. *the boy touches the girl* became *the girl touches the boy*) to ensure that responses were not memorised.

To represent the five stimulus sentences, we created five sets of pictures (12.7 × 17.8 cm) with 4 pictures in each set for a total 20 colour pictures. The four pictures for each stimulus sentence set were displayed equidistant from one another in each corner of a 60 × 60 cm board. For each question, the location of the target picture was moved to ensure that participants would not fixate on a particular location. Each set of pictures contained one picture referring to the stimulus sentence together with three distracter pictures. For the stimulus sentence (e.g. *the boy holds the girl*), the distracter pictures consisted of one picture of the subject and object reversed (e.g. *the girl holds the boy*) and two pictures of the same noun as both subject and object (e.g. *the boy holds the boy* and *the girl holds the girl*).

tDCS

In pre-tDCS testing, the unit was placed on the participant's head without current flow to preserve familiarity with the treatment setting. After the pre-tDCS syntax testing, the tDCS unit was activated. To ensure safety, all participants received a total current density of 0.08 mA/cm^2 within the 30-minute treatment period. The tDCS was administered through a battery-driven direct current stimulator with an anodal (positive) and a cathodal (negative) lead. The tDCS unit was placed into a fanny pack around the participant's waist. The leads from the tDCS unit were inserted into two 5 × 5 cm saline-soaked sponges held to the scalp by a headband. The anodal (positive) lead was placed over the DLPFC corresponding to F3 of the 10–20 international system for EEG electrode placement. The cathode (negative) was used as a reference lead and was placed over the right supraorbital region.

Statistical analysis

A total of 10 participants were tested in this repeated measures study. We requested a statistician blinded to this study to evaluate the data. Descriptive statistics were initially calculated to measure frequencies and percentages for the raw data correct score count pre-/post-tDCS for the participants according to type (vocabulary and syntax). Parametric paired *t*-tests were used to independently compare pre-/post-tDCS scores on the same participants for the number of correct responses to the vocabulary and syntax tests. In the paired *t*-tests of both the vocabulary and syntax tests, the null hypotheses were that there was not a statistically significant increase in mean scores from pre-tDCS to post-tDCS. The alternative hypotheses were that there would be statistically significant increases in the mean scores from pre-tDCS to post-tDCS. Assumptions for the parametric paired *t*-tests included continuous data, normality and absence of outliers. The data were ordinal and not continuous in nature: therefore, the correct score outcomes were transformed via a square root transformation before the paired *t*-test was conducted. For vocabulary test, results of the analysis were back-transformed by squaring the results for reporting purposes.

We investigated the normality of both vocabulary and syntax data using the Kolmogorov–Smirnov tests of normality (KS test) and normal QQ plots of the root-transformed correct score count data. For the vocabulary test, we investigated the presence of outliers through a visual inspection of box plots for the root-transformed data. Due to the small sample size, we also performed Wilcoxon signed rank tests on both the vocabulary and syntax scores pre- to post-tDCS.

After reviewing the descriptive data of vocabulary and syntax scores, we elected to compare those participants who had scored 100% pre- and post-tDCS vocabulary scores ($n = 4$) with those who did not ($n = 6$). We performed the non-parametric Mann–Whitney *U*-test (MWU) on the ordinal-dependent variable outcomes of post-tDCS syntax scores to measure two groups: (a) those who scored 100% pre- and post-tDCS on the vocabulary ($n = 4$) test; and (b) those who did not score 100% pre- and post-tDCS on the vocabulary ($n = 6$). The MWU compared these two groups on the outcome of *post-tDCS syntax scores only*. Assumptions for the MWU are independent observations in the two independent groups. MWU does not make assumptions regarding the distribution of the data. The null hypothesis was that there would not be a statistically significant difference in median post-tDCS syntax scores between the two groups of (a) those who scored 100% pre- and post-tDCS on the vocabulary measure versus (b) those who did not. The alternative hypothesis was that there would be a statistically significant difference in median post-tDCS syntax scores between the two groups of (a) those who scored 100% pre- and post-tDCS on the vocabulary measure versus (b) those who did not.

Results

All participants tolerated the treatment without any side-effects. Participants were not resistant to the treatment protocol. All 10 participants were included in the final analysis. The descriptive measures are shown in Tables I–III and Figures 1 and 2. They demonstrate significant group differences (pre-/post-tDCS) in both vocabulary and syntax scores.

The results of pre-/post-tDCS correct score counts on the vocabulary test were compared. The KS test returned normality at the $p = 0.01$ level of significance. Normal QQ plots indicated normal distribution of the data. Therefore, the normality assumption was considered not violated. No outliers were found and assumption of absence of outliers was not violated.

The one-tailed paired *t*-test on the root-transformed data indicated that post-tDCS mean vocabulary scores (mean 10, SD 0.0) were significantly higher than pre-tDCS mean vocabulary scores (mean 8.60, SD 1.43), $t\ (9) = -3.026$, $p = 0.007$. The effect size of the difference

Table I. Frequencies and percentages of correct score counts according to type (vocabulary vs. syntax) and time (pre vs. post) of test ($n = 10$).

Test/time of measure	Frequency	%
Vocabulary/pre-test[a]		
Score of 6	1	10.0
Score of 7	1	10.0
Score of 8	3	30.0
Score of 9	1	10.0
Score of 10	4	40.0
Vocabulary/post-test[a]		
Score of 10	10	100.0
Syntax/pre-test[b]		
Score of 1	4	40.0
Score of 2	5	50.0
Score of 3	1	10.0
Syntax/post-test[b]		
Score of 3	2	20.0
Score of 4	4	40.0
Score of 5	4	40.0

Notes: All subjects obtained a correct score count of 10 on the vocabulary post-test.
[a]Possible range for vocabulary correct score counts = 0–10.
[b]Possible range for syntax correct score counts = 0–5.

Table II. Measures of central tendency of correct score counts according to type (vocabulary vs. syntax) and time (pre vs. post) of test ($n = 10$).

Test/time of measure	Mean	SD	Median	Sample range
Vocabulary[a]				
Pre-test	8.60	1.43	8.50	6–10
Post-test	10.00	0	10.00	10–10
Syntax[b]				
Pre-test	1.70	0.67	2.00	1–3
Post-test	4.20	0.79	4.00	3–5

Notes: All subjects obtained a correct score count of 10 on the vocabulary post-test.
[a]Possible range for vocabulary correct score counts = 0–10.
[b]Possible range for syntax correct score counts = 0–5.

was large: $d = 0.96$ (Cohen, 1992) and we rejected the null hypothesis. There was sufficient evidence to indicate a significantly higher post-tDCS mean vocabulary score over the pre-tDCS mean score. The results of the Wilcoxon signed rank test on the ranked vocabulary scores pre-/post-tDCS were also statistically significant, $Z = -2.226$, $p = 0.013$, confirming the results of the paired *t*-test.

The results of the comparison of pre-/post-tDCS score counts on the syntax test were calculated. The KS test returned normality at $p = 0.01$ level of significance. Normal QQ plots indicated normal distribution of the data; therefore, the normality assumption for syntax scores was not violated. Results of the one-tailed paired *t*-test indicated that post-tDCS mean syntax scores (mean 4.20, SD 0.79) were significantly higher than pre-tDCS mean syntax scores (mean 1.70, SD 0.67), $t\,(9) = -8.801$, $p < 0.0005$. The effect size of the difference was

Table III. Pre-test, post-test and percentage change in pre- versus post-test scores for the vocabulary and syntax measures according to study subject ($n = 10$).

	Number correct		Percent change
Measure/subject	Pre-test	Post-test	Pre- to post-test
Vocabulary[a]			
1	10	10	0.00
2	10	10	0.00
3	10	10	0.00
4	10	10	0.00
5	8	10	25.00
6	7	10	42.86
7	6	10	66.67
8	8	10	25.00
9	9	10	11.11
10	8	10	25.00
Syntax[b]			
1	1	3	200.00
2	2	4	100.00
3	2	3	50.00
4	1	4	300.00
5	2	5	150.00
6	1	5	400.00
7	2	5	150.00
8	3	5	66.67
9	2	4	100.00
10	1	4	300.00

Notes: [a]Possible range for vocabulary correct score counts = 0–10.
[b]Possible range for syntax correct score counts = 0–5.

large: $d = 2.78$ (Cohen, 1992) and we rejected the null hypothesis. There was sufficient evidence to indicate a significantly higher post-tDCS mean syntax score over the pre-tDCS mean score. The results of the Wilcoxon signed rank test were statistically significant, $Z = -2.809$, $p = 0.003$, confirming the results of the paired t-test.

The MWU test results for the post-tDCS syntax scores of two participant groups from the vocabulary test were significant ($Z = -2.282$, $p = 0.022$). This indicated that the participant group (a), those who scored 100% pre- and post-tDCS on the vocabulary measure, had significantly lower syntax scores (*mean rank* = 3.00, *median* = 3.5) than did the participant group (b), those who did not score 100% (*mean rank* = 7.17, *median* = 5.0). We rejected the null hypothesis, because there was sufficient evidence to indicate a significant difference in scores between these two independent groups.

Discussion

To refer to autism as an epidemic is arguable, yet autism affects a disproportionately large number of individuals and its global prevalence is increasing at a disturbing rate. Epidemiological data concerning autism are difficult to calculate. The prevalence of children who do not have functional language is estimated to be in the millions. As adults, 50% of people with autism have a significant absence of verbal language (Foudon et al., 2008). This presages an international concern for global healthcare.

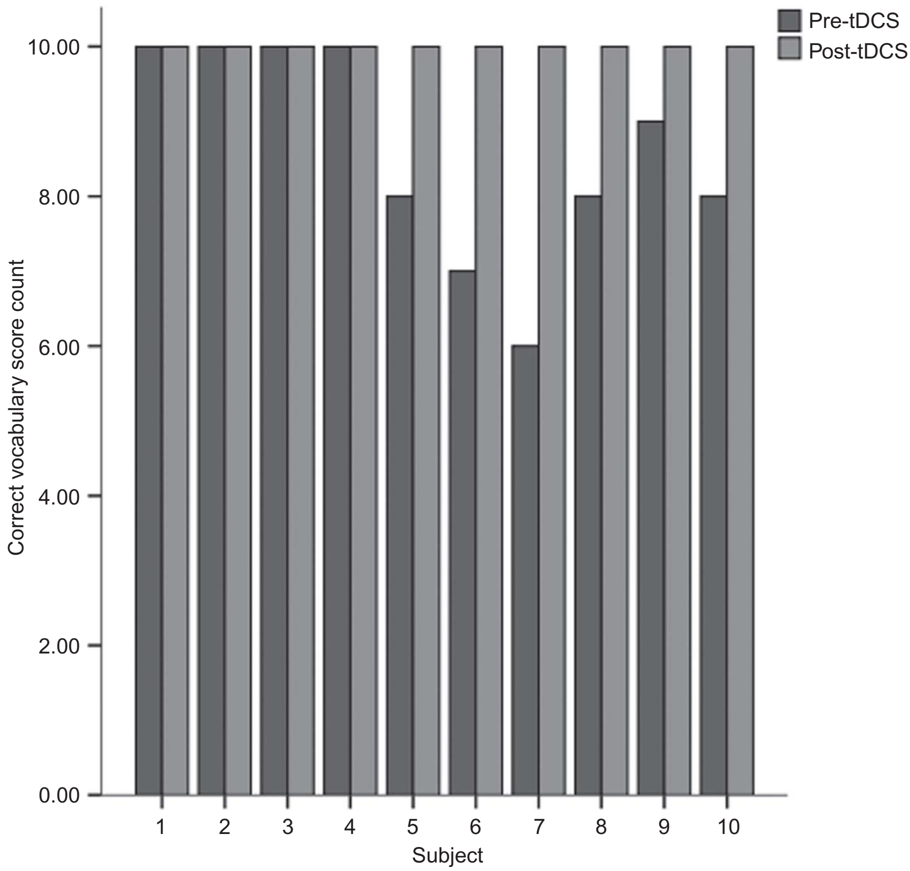

Figure 1. Number of correct responses for vocabulary pre-tDCS and post-tDCS according to study participant.

Many treatment interventions for general language dysfunction for children with autism have had limited success. A less obvious reason for poor outcomes of previous therapies may be a lack of appreciation of the importance of grammar acquisition in producing functional and meaningful language as part of children's cognitive development. A prerequisite for semantic intentions stemming from cognitive development would be the incidental acquisition of linguistic competence, that is, implicit, automatic grammatical procedures that permit the comprehension of utterances (Paradis, 2004). At the most fundamental level, acquiring syntax involves classifying lexical items into syntactic categories. One of the most challenging questions about the development of language in TD children is the appropriation of syntax in their first language. This question becomes more challenging in children with classical autism. Implicit syntax training, therefore, would be a necessary addition to behavioural and speech-language therapies for these children.

In this research investigation, we focused on syntax acquisition in minimally verbal children with autism who had achieved prelinguistic behaviours thought to be predictive of language acquisition. We used online tDCS in controlled-test conditions to positively neuromodulate the acquisition of basic syntax. Despite a relatively small sample size of participants, non-parametric tests confirmed a large difference in pre-tDCS and post-tDCS syntax

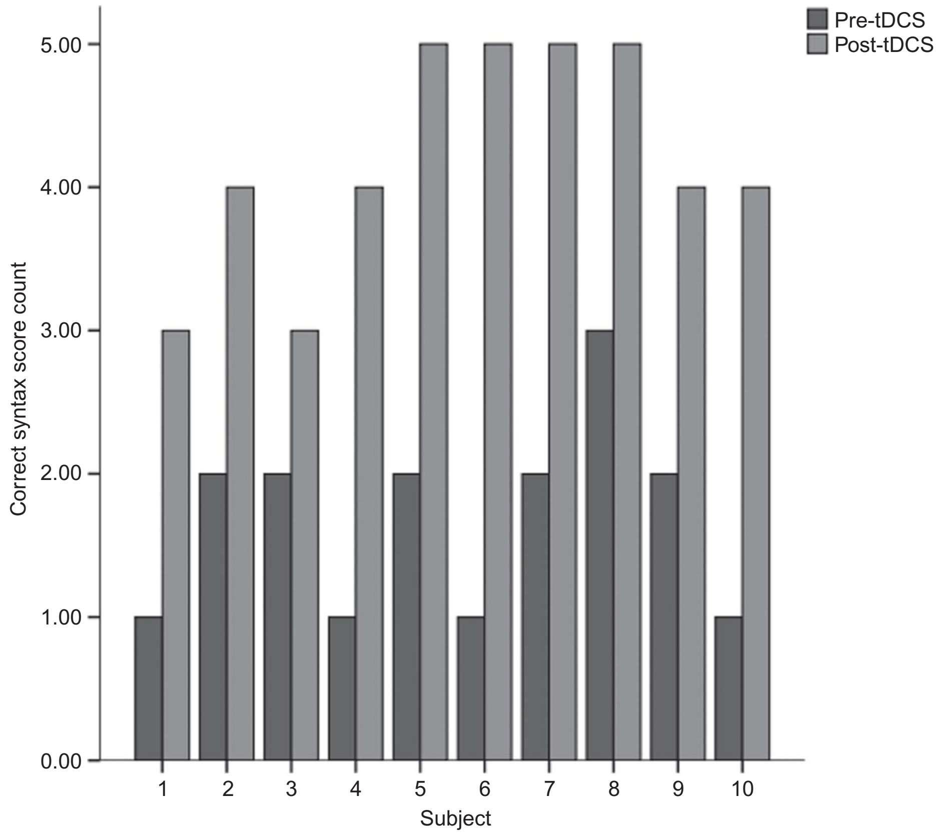

Figure 2. Number of correct responses for syntax pre-tDCS and post-tDCS according to study participant.

comprehension test scores. Not all of the children achieved 100% accuracy on basic SVO sentences after treatment. Acquisition of syntax is a slower process than appropriation of vocabulary. The procedural improvement in performance on this brief syntax task may represent a rapid, incomplete early phase of syntactic (procedural) learning that generalises over time to other syntactic tasks, consistent with how the BG process procedural rules.

A review of vocabulary scores highlighted four participants who achieved 100% accuracy on both the pre- and post-tDCS tests. We queried the significance of this finding. We used the MWU to investigate any relationship between scores on the vocabulary test and the syntax test. The MWU specifically compared pre-tDCS vocabulary scores to post-tDCS syntax scores. The results showed that the participants who had perfect scores on the vocabulary test performed worse on the syntax test. This is not interpreted to mean that high vocabulary scores predict low syntax scores. Rather we interpret this finding to represent that in minimally verbal children with autism, there may not be positive correlations between vocabulary size and appropriation of syntax. Children with autism with particularly weak procedural memory rely to a great extent on declarative memory and do well on declarative vocabulary learning, a skill they cannot apply to syntax acquisition, and hence do poorly. The better their declarative memory, the more they rely on the declarative memory system to solve tasks (as do normal L2 learners after the age of six or seven). This is described within the framework of the declarative/procedural model of Ullman (2004).

We encourage future studies to help clarify the issue of lexicon size and acquisition of syntax in this population of children.

Some of the theories that are thought to be involved in language appropriation in children with autism include an incomplete theory of mind (Whiten, Irving, and MacIntyre, 1993) and deficits in executive function (Ozonoff, Pennington, and Rogers, 1991). We chose to stimulate the DLPFC, a cortical area known to be involved in executive function. This is a cognitive system that is thought to control and manage other cognitive processes. It is believed to be responsible for problem-solving of novel situations where responses are not well rehearsed, for situations involved in error detection and for inhibiting habitual or irrelevant responses. Suboptimal executive function is thought to be partially responsible for the language dysfunctions found in children with autism (Aron, 2007).

The DLPFC, through corticostriatal pathways, stimulates the release of dopamine and glutamate receptors in the BG. Transcranial stimulation of the DLPFC may have facilitated connectivity in the procedural 'grammar circuitry' of the BG. We believe this to be the overarching reason why we were able to achieve syntax acquisition in this study: neurotransmitter release and neural plasticity with the online use of tDCS. Future neuroimaging studies would be needed to demonstrate areas of brain plasticity associated with the use of neuromodulation during specific grammar tasks. Future linguistic studies are needed to establish what types of requisite linguistic input, such as temporal aspects of prosodic features, facilitate syntax acquisition in children with autism.

As treatment interventions, such as tDCS, improve language function in autism, there should be continual assessments of children's levels of grammar acquisition. Thought should be given to utilise the BAT's scoring system in an effort to assess syntax comprehension of increasingly complex levels of syntactic structure. The notion of thereby creating *divisions and subdivisions* of language dysfunction for children with autism, which do not currently exist, seems very important from diagnostic, pedagogical and therapeutic points of view. Accurate divisions of language levels would help assess the trajectory of changes in children with autism. Analysis of non-normative trajectory data could facilitate the discovery of particular events that 'trigger' known alterations from normative trajectories. In addition, a modified BAT might assess trajectory of changes in bilingual children with autism and could provide a necessary new data pool for language dysfunction in global autism.

According to the United States (US) Census 2000, about 10 million children speak a language other than English at home (US Census Bureau, 2003). The world census estimates the world population to be between 6 and 7 billion people (US Census Bureau, 2010). It is commonly thought that 60–75% of the world is bilingual (estimated at 5 billion) and 22% of the world bilingual population are children less than 15 years of age (estimated at 1 billion). Approximately 15% of children with autism treated at the CMBS are bilingual which reflects this prevalence. With the prevalence of autism estimated at about 1/150 globally, a gross estimate of the number of bilingual children with autism is 6 million.

The BAT was originally designed to assess the languages of a bilingual or multilingual person with aphasia in an equivalent way. According to Paradis, any version of the BAT is an adaptation of the battery to the 'structure and culture of a particular language' and he reminds us that 'there is no end to how much it can be adapted to a particular dialect, a given population or a specific patient' (http://www.mcgill.ca/linguistics/research/bat/). We believe bilingual patients with autism represent a large population of patients with an inability to use or understand language and are under-diagnosed and under-treated. Bilingual children with autism will benefit from a language test in which criteria of cross-language equivalence vary with each task. We believe the BAT modified for children with autism, yet upholding the carefully structured design of the original BAT, to be the test of choice for this population. The design of a modified bilingual *autism* test should be proposed to the authors of the original BAT for future research on bilingual children with autism.

There is a general lack of knowledge about autism across the world and an inadequate understanding of the nature of its accompanying language difficulties. We need to target the awareness of autism in different cultures and communities in an effort to improve and extend services, to increase research support and to encourage improved social inclusion of children with autism. Capitalising on the utility of the BAT as a premiere diagnostic tool for bilingual language assessment for children with autism across the world may provide a means to accomplish these objectives.

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