THE MODULATION OF NOVEL WORD ACQUISITION WITH THETA-BAND TRANSCRANIAL ALTERNATING CURRENT STIMULATION

Zhuravleva A.A.
(aazhuravleva@hse.ru),

Stupina E.A., Malyutin S.A.
Center for Language and Brain, HSE University (Moscow, Russia)

Novel word acquisition is a crucial part of both first language acquisition (L1) and foreign language learning (L2). On the neural level, novel word acquisition relies on primarily frontotemporal networks [Bakker-Marshall et al., 2018]. However, less is known about how these regions interact on the neurophysiological level, and how different types of neural oscillations support the functional linkage between brain regions involved in novel word acquisition. Most studies on novel word acquisition were conducted via neuroimaging methods [Bakker-Marshall et al., 2018] which can reveal correlational but not causal links between neural and behavioral processes. On the other hand, endogenous neural activity can be directly modulated via non-invasive neurostimulation methods. Among them, transcranial altering current stimulation (tACS) allows to enhance neural oscillations at a target frequency. Only few studies investigated novel word acquisition using tACS [Ambrus et al., 2015; Antonenko et al., 2016]. This paper aims to do so and investigate the role of theta-band neural oscillations in the left frontotemporal network in novel word acquisition. This is one of the first studies to investigate modulatory effect of tACS on novel word acquisition.

For the tACS experiment, we developed a new word acquisition paradigm that uniquely combines explicit word presentation, active acquisition tasks, and a set of diverse testing tasks probing novel word knowledge on different levels of processing. The paradigm modelled novel word acquisition during L2 learning and consisted of 80 pseudowords (PW) developed by Stupina and Chrabaszcz [Stupina, Chrabaszcz, 2020] paired with 80 Russian nouns [Akinina et al., 2015] as their meanings. The paradigm included two phases: acquisition and testing. The acquisition phase included passive PW-L1 presentation and two active acquisition tasks designed to promote learning by active retrieval: 3-alternative-forced-choice (3-AFC) and definition-cued recall. The testing phase consisted of three tasks: recognition task, definition-cued recall, and semantic decision task. Recognition task tested whether participants accurately recognized novel items. Definition-cued recall tested consolidation of novel word forms and meanings in the long-term memory. Semantic decision tested integration of a novel word into the existing lexicon. We validated the paradigm in an online study to estimate the difficulty of the tasks.

Further, we conducted a tACS study using the paradigm. Thirty volunteers aged between 18 and 41 years old (M_{age} = 27.8, *SD* = 9.19) participated in two sessions separated by a 4-day interval. During each session, tACS in the theta-range frequency or sham (placebo) stimulation was applied. Each session included a word acquisition phase during tACS/placebo, followed by an immediate testing phase, as well as a delayed testing phase four days later. TACS was applied with the StarStim transcranial electric stimulation device (Neuroelectrics, Spain) for 20 minutes (during the full duration of the acquisition phase) at the intensity of 500 μA per electrode in the theta-band frequency (5.5 Hz) with no phase shift (in phase, 0°). The electrodes were placed over the F7 and P7 electrode positions corresponding to the perisylvian regions crucial for language processing [Bakker-Marshall et al., 2018]. The analysis aimed to test the main effect of tACS on accuracy and reaction time (RT). Data processing and descriptive analysis were performed in Python 3.7. Statistical analysis was performed in the R software using *lme4* package: effects of tACS on accuracy and RTs in each task were estimated using (generalized) linear mixed-effects models via the *lmer* and *glmer* functions.

The paradigm validation revealed that participants' performance in all tasks was neither at floor nor at ceiling, with mean accuracy varying from 25.9% (*SD* = 23.5%) in definition-cued recall in the immediate testing to 85.4% (*SD* = 12.2%) in the 3-AFC task in the acquisition phase. Secondly, the data confirmed different difficulty level of tasks and, specifically, higher difficulty of the recall task evident from lower accuracy and increased RT. Thus, the paradigm was proven to have an optimal difficulty level to be sensitive to potential effects of non-invasive brain stimulation. The results of the tACS experiment are presented in Table 1. Statistical analysis revealed no significant main effect of tACS compared to the sham condition in either accuracy or RT in any experimental task.

Table 1. Behavioral results of tACS experiment

Session	Task	Condition	Accuracy Measure	Accuracy M	Accuracy SD	RT, ms M	RT, ms SD	RT, ms Min	RT, ms Max
Acquisition	3-AFC	Real	Accuracy, %	88.96	9.13	2233	555	919	3438
		Sham		88.17	8.80	2218	550	847	3467
	Recall	Real	Score	0.55	0.16	4445	1079	2087	6537
		Sham		0.52	0.15	4749	1314	2826	7771
Immediate testing	Recognition	Real	Accuracy, %	79.69	13.45	1916	575	846	3441
		Sham		79.38	12.65	1911	545	717	3457
	Recall	Real	Score	0.51	0.16	4942	1186	2541	7472
		Sham		0.51	0.16	4568	1206	2894	7885
	Semantic decision	Real	Accuracy, %	69.44	26.16	2030	749	392	3957
		Sham		73.48	17.92	1951	770	436	3962
Delayed testing	Recognition	Real	Accuracy, %	66.77	10.88	1875	578	604	3465
		Sham		68.91	13.07	1918	541	85	3420
	Recall	Real	Score	0.48	0.18	4664	1209	2632	7776
		Sham		0.47	0.18	4679	1126	2868	7302
	Semantic decision	Real	Accuracy, %	73.64	12.73	1701	786	10	3912
		Sham		73.63	13.39	1643	725	57	3863

The absence of significant effects of tACS can be due to several issues related to the targeted cognitive function, as well as frequency, phase, and spatial parameters of the protocol. Firstly, we applied tACS during the acquisition phase based on empirical evidence of enhanced theta-band activity both during encoding and retrieval in novel word acquisition. However, several studies reported higher involvement of theta-band oscillations in retrieval [Klimesch et al., 2001]. Secondly, we applied theta-band tACS over cortical structures related to language processing. However, theta-band oscillations are thought to arise from the hippocampus and subcortical structures which cannot be non-invasively stimulated in humans. Thirdly, we used in-phase synchronization of the stimulated brain areas. Still, little is known about how frontotemporal parietal regions integrate during novel word acquisition, so anti-phase stimulation can be potentially more effective. Finally, we applied 5.5 Hz tACS and used a single-frequency sham-controlled design. Still, there is evidence of different functional specificity of low-frequency and high-frequency oscillations within the theta band. Thus, further research needs to address whether novel word acquisition can be modulated by tACS with a different choice of spatial, phase, and frequency parameters.

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