Australian Government
Department of Defence
Defence Science and
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Transcranial Direct Current Stimulation: Implications for Command in the Australian Defence Force

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DSTO Science and Technology for Safeguarding Australia

B. L. U. F. / Overview

- tDCS (transcranial direct current stimulation) is acceptably safe to use
- Considerable potential for use in the ADF to support:
  - C2 decision making
  - Education and training
  - Manpower efficiency
  - Individual warfighter capability
- **Planning, policy**, and more **research** is required in some areas.

What is tDCS?

- Transcranial Direct Current Stimulation (tDCS)
- Non-invasive technique
- Applies direct current (DC) to the head
- Level of electricity less than the amount required to power a small torch
- **Can enhance a number of cognitive and motor areas**
- **Verum & Sham stimulation (deals with 'placebo')**

Image source: http://www.neuroconn.de/dc-stimulator_plus_en/

Potential for use in Defence

- New directions in human factors research
- Directly increase human capability
- Enhances areas of cognition and motor performance directly relevant to ADF
- Increase warfighter capability and C2 decision making
- Improve manpower efficiencies and reduce requirements

Increasing survivability

Area	Reference	Conclusion
Threat detection	Medina et al. (2012)	Active group displayed faster reaction times than reverse polarity and sham groups
Deceptive capabilities	Karim et al. (2010)	Active group were better at deceiving than sham
Hunger resistance	Goldman et al. (2011)	Active group displayed a larger change in inability to resist food than sham
Reflexes	Jacobson et al. (2011)	Active group exhibited quicker reaction times than sham
Impulse control	Ditye et al. (2012)	Active groups displayed more careful (less impulsive) driving behaviour than baseline

Motor enhancement: Reaction time

- Active tDCS group 32 milliseconds quicker than control group motor reaction time task*
- Difference between elite police officers and rookie police officers is around 13 milliseconds (Vickers & Lewinski, 2012).
- Therefore an improvement of 32ms could make a vital difference **

- * Experimental study from Pascual-Leone et al. (2012)
- ** Discussion of effect sizes from Levasseur-Moreau et al. (2013)

Physical (motor) enhancement

Area	Reference	Finding
Motor precision	Buetefisch et al. (2011)	Increased accuracy on highly demanding precision tasks, but no significant difference on less demanding tasks
Motor strength	Tanaka et al. (2009)	Active group displayed greater strength compared with reverse polarity and sham groups
Movement acceleration	Teo et al. (2011)	Active group reached higher peak acceleration level than baseline
Muscular endurance	Cogiamanian et al. (2007)	Active group displayed increased endurance compared with sham
Motor learning	Nitsche, Schauenburg, et al. (2003)	Active group were faster at executing implicitly learned sequences than participants in control groups
Everyday motor functions	Williams et al. (2010)	Active group were faster than sham

Perception

Area	Reference	Finding
Vision	Kraft et al. (2010)	Anodal group yielded a significant increase in contrast sensitivity within 8° of the visual field compared with sham
Auditory perception	Tang and Hammond (2013)	Active stimulation degraded frequency discrimination compared with sham
Perception of pain	Aslaksen et al. (2014)	Active group experienced an analgesic effect on high-intensity heat pain
Tactile perception	Ragert et al. (2008)	Active group displayed improved somatosensory discrimination compared with sham

Cognitive enhancement: Insightful decision making

Chi & Snyder (2011) “Facilitate insight by non-invasive brain stimulation”

- Investigated whether non-invasive brain stimulation can facilitate insight

Insight problem:

Type	False Statement	Solution
1	III = IX − I	III = IV − I
2	VI = VI + VI	VI = VI = VI
3	IX = VI − III	IX − VI = III

- Results (Type 2 questions):
  - 20% of control group able to solve type 2 problem
  - 60% of active group solved type 2 problem

Cognitive enhancement: Decision making

Area	Reference	Finding
Problem solving	Chi and Snyder (2011)	Active group was three times more likely to solve the problem than sham group
Planning	Dockery et al. (2009)	Anodal group completed the task faster than sham, and cathodal group completed the task more accurately than sham
Probabilistic assessment	Hecht et al. (2010)	Active group were quicker to select the most frequent alternative compared with control groups

Cognitive enhancement: Memory

Area	Reference	Finding
Working memory	Gladwin et al. (2012)	Healthy subjects were faster when they received active tDCS compared with sham
	Jeon and Han (2012)	Active group displayed enhanced working memory compared with sham
	Flöela et al. (2012)	Active group displayed higher level of accuracy than sham
Declarative memory	Marshall et al. (2004)	Anodal stimulation during SWS-rich sleep increased the retention of word pairs, compared with sham and stimulation during wake period
Long term memory	Javadi and Cheng (2012)	Anodal stimulation resulted in significantly more words recognized compared with cathodal and sham stimulation

Cognitive enhancement: Learning

Area	Reference	Finding
Associative learning	Flöel et al. (2008)	Active group displayed faster associative learning than sham
Categorization learning	Ambrus et al. (2011)	Active groups displayed decreased performance in categorization of prototypes

- USAF use described in Scientific American (2011):
  - Found that learning time (of complex drone guiding task) was cut in half by delivering 30 minutes of tDCS
  - “TDCS not only accelerated learning, pilot accuracy was sustained in trials lasting up to 40 minutes” - Andy McKinley et al. (Air Force Research Laboratory at Wright - Patterson Air Force Base)
- DARPA experiments described in New Scientist (2012):
  - Training became easier for participants who describe “flow” state
  - tDCS cut the time required to reach pro level of marksmanship by half

Cognitive enhancement: Attention

Area	Reference	Finding
Sustained attention	Nelson et al. (2013)	Active group displayed enhanced accuracy, but slower reaction time
Focused attention	Bolognini et al. (2011)	Active group displaced improved attention
Selective attention	Clark et al. (2012)	Active group identified more correct targets, experienced fewer false alarms, and completed the task quicker than sham
Spatial attention	Loftus and Nicholls (2012)	Active group demonstrated reduction in pseudoneglect compared with control groups
Attentional switch	Vanderhasselt et al. (2006)	Active group switched attention faster than sham

Safety

- Thousands of people have participated in tDCS across hundreds of studies
- Most severe adverse effects found was skin abrasions under the electrodes
- No other serious or ongoing side effects
- The most commonly reported incidents of minor discomfort (Brunoni et al., 2011):
  - Mild itching/burning sensation (most common)
  - Mild headaches (primarily in frequent headache sufferers)
  - Fatigue (uncommon)
  - Nausea (rare)

Risk

- Risk factors:
  - Precise path of current not well understood
  - Current often flows into adjacent brain regions causing unwanted effects
  - Individual differences
  - Second Order effects
  - Untested in military environment
- Possibility of unanticipated effects – research needed
- Dangerous in certain situations (e.g. combat)

Mood and personality

Paper	Area Influenced by Stimulation
Fecteau, et al. (2007)	Risk-taking and reward seeking behaviour
Priori et al. (2008)	Neural mechanisms associated with lying and deception
Ferrucci et al. (2009)	Depression, poor mood, and sadness
Young et al. (2010)	Capacity to make moral judgements when judging attempted harms
Maeoka et al. (2012)	Emotional aspects associated with pain

- Ethics of changing people's moral thought and behaviour
- Question of unpredictable behaviour and decision making in dangerous military situation

Private use in Defence

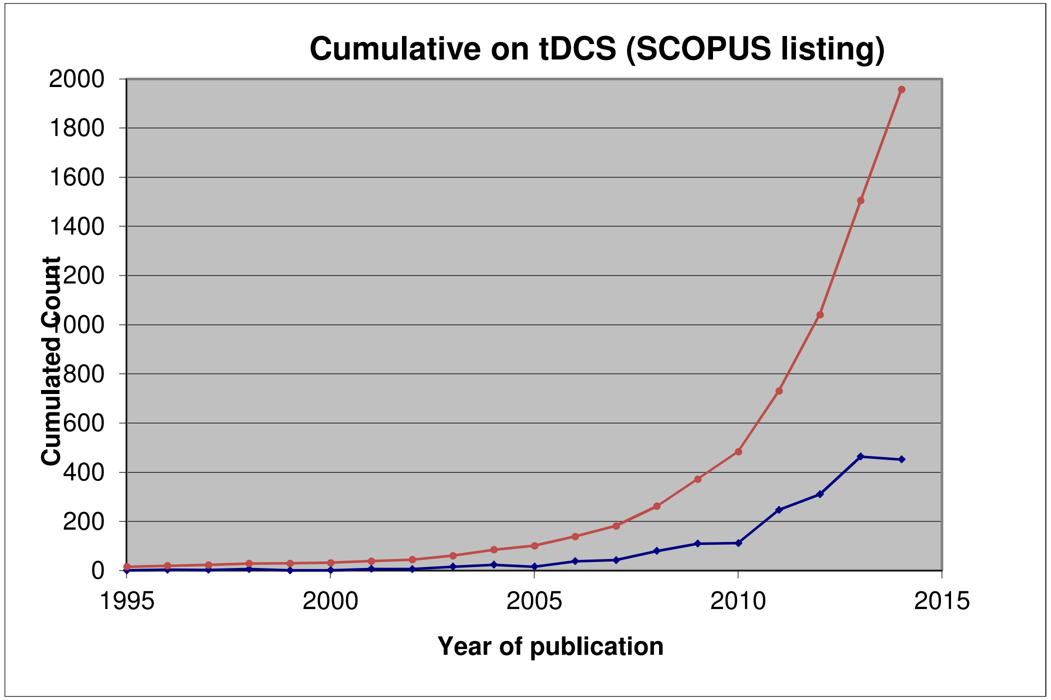
Reasons self-administering tDCS is likely:

- tDCS is becoming more popular and well known
- Easy to buy online or find DIY instructions
- Warfighters more likely to experiment

Why it's an issue:

  - Lack of safety features and component redundancy
  - Lack of safe administration guidelines
  - Lack of knowledge of appropriate electrode montages (some can be dangerous)

Research effort to date



Roughly equal numbers of clinical and healthy subject populations.

Reported (positively) in everyday media (ABC, New Scientist,…)

It's new, in current form. (but builds on centuries of physiology and electricity investigation)

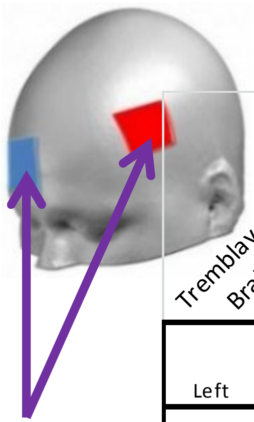
2000 papers in 15 years and climbing (because it works)

Only a couple of instances of other than transient Adverse Effect from single application in *scientific* literature – skin redness, small lesion

tDCS to DorsoLateralPreFrontal Cortex

"The uncertain outcome of prefrontal tDCS" Tremblay et al 2015 review

"… tDCS over DLPFC affects a wide array of cognitive functions, with sometimes apparent conflicting results"



Tremblay et al 2014 Brain Stimulation, 7, 773-783 DLPFC

Left	Right	Reference	WM: unspec	Executive Function / Cognitive: flexibility	Executive Function / Cognitive: planning	Executive Function / Cognitive: control(affect)	Executive Function / Cognitive: impulsivity/control	Attention: behaviour	Attention: control	Attention: attention	Attention: unspec	Verbal/Semantic: verb.priming	Verbal/Semantic: verb.fluency	Verbal/Semantic: semantic process / comprehension	Verbal/Semantic: word retrieval	Verbal/Semantic: lying	Verbal/Semantic: resp.to lying	Fear/Stress/Pain: memory creation	Fear/Stress/Pain: threshold	Affect/Emotion: perception(affect)	Affect/Emotion: control(affect)	Affect/Emotion: resp. to lies	Memory: verbal	Memory: visuospatial	Memory: unspec	Learning: categorical	Learning: automaticity	Learning: unspec	Risk Taking: lying	Risk Taking: confidence	Risk Taking: unspec behav	DM	Punish/Control Behav: eating	Punish/Control Behav: craving	Punish/Control Behav: resp.to unfair behav
Cathode	--	Anode	+ -	+	-							-	-	+				-					-									/			
	Cathode	Anode			+	+	-			-									+		+														-
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	Anode	Cathode	+				+												+		+			+	+						/-				-
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Cathode	Anode			+			+			-				+		+														+	-		+	+	
An/Cath	Cath/An																												+						

detection

Future directions

- Defence research program into the technology focusing on research areas of interest to ADF
- Developing Defence policy and doctrine
- Eventual use:
  - Motor enhancement
  - Perception
  - Survivability related areas
- Suitable areas for use in the near future:
  - Training/education
  - Command and control

Brain functions that can be enhanced (so far…)

- Simple picture naming
- Memory for words
- Recalling people's names
- Remembering location of objects
- Increase in duration of vigilance (radar watching)
- Episodic memory
- Manual dexterity/ Motor learning
- Prototype learning
- Focussed Attention ("in the zone")
- Working memory (hold and process several elements of information for a purpose)
- Detection of covert threats (especially in novices)
- Verbal fluency
- Planning
- Analogical reasoning
- Solving insight problems
- Risky choice reduction
- Cognitive bias adjustment

- ***BUT, look for negative effects, second order effects,***
- ***tolerance, individual differences,***
- ***RESEARCH needed.***

*** may alter mood**

Further information

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Paper:

Davis, S. E., and Smith, G. A. (2014). Ethical and Safety Considerations of Transcranial Direct Current Stimulation Use in the Military. DSTO-DP-1272. *Joint & Operations Analysis Division. Defence Science and Technology Organisation.*