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The effectiveness of Transcranial Direct Current Stimulation as an intervention to improve empathic abilities and reduce violent behavior: A literature review

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ABSTRACT

Background: Empathy can be seen as an individual factor decreasing the probability of violent, criminal behavior, whereas a lack of empathy is seen as an increasing factor to antisocial behavior. Antisocial behavior, especially aggression and impulsive behavior, is associated with dysfunctions in the prefrontal cortex. There has been a growing interest in using Transcranial Direct Current Stimulation (tDCS) as an intervention to modulate brain regions of interest and increasing activity in damaged brain areas. This paper reviews the evidence about using tDCS as a potential intervention to increase empathic abilities and decrease antisocial behavior in violent offenders.

Objective/methods: This literature review is conducted to examine what is currently known about how tDCS may modulate empathic abilities and aggressive behavior. Articles in which tDCS was used to modulate empathic abilities and/or modulate violent behavior were selected. Brain areas of interest were the Ventromedial Prefrontal Cortex and the Dorsolateral Prefrontal Cortex.

Results/conclusions: Literature collected so far support the application of tDCS as a potential tool to increase empathic abilities and reduce violence in forensic patients, especially when targeting the vmPFC. Further research on the vast parameter space of tCS (e.g. stimulation intensity, electrode location, polarity) is needed to consolidate tDCS as a tool in forensic science.

1. Introduction

Empathy can be described as the ability to share the mental states of other individuals, facilitating the motivation, action and affections of others (Hein and Singer, 2008; de Vignemont & Singer, 2006). According to the models of Blair (Blair, 2001, 2005; Blair et al., 2006), individuals with less empathic abilities may be less susceptible and motivated to inhibit violent behavior, because violence is inhibited by empathy for another person. It is hypothesized that less empathy leads to a higher risk of violence. Empathic abilities are crucial for social enhancement, social interactions and relationships, and for our emotional and social life (Bernhardt and Singer, 2012). It has indeed been found that a deficit in empathic abilities is associated with antisocial and deviant behavior and with that a higher risk of violence (Preller et al., 2014). Blair (1995) has suggested that humans might hold a functional mechanism to inhibit violence: the violence inhibition mechanism (VIM). This cognitive mechanism can, when activated by distress cues, such as sad facial expression or the visual or auditory cues of tears, mediate in the activation of aggression. Blair proposed that the VIM is a precondition for the development of (1) moral emotions such as remorse, guilt and sympathy, (2) non-violent behavior, and (3) the moral and conventional distinction during childhood. A lack proper working of the VIM can lead to the antisocial behavior, including violence.

A meta-analysis of Jolliffe and Farrington (2004) revealed indeed a negative correlation between empathy and offending. The ability to not empathize with someone else, including the suppressing of an emphatic response (McGrady et al., 2008) is regarded as a cause of antisocial behavior (Lovett and Sheffield, 2007). A recent study reported that lower empathy predicted moral disengagement and juvenile petitions for violent crimes (Galan et al., 2017). In addition, Winter et al. (2017) showed that men with a history of aggressive behavior showed

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diminished empathic responses. Further, in studies of criminal offenders, male offenders demonstrate lower empathy levels than males in control samples. In a study of Heilbrun (1982), male prisoners with histories of violent behavior were assessed and results showed that lower levels of empathy were associated with physical aggression. Other studies show that sex offenders exhibit low levels of empathy (Geer et al., 2000; Scully, 1988; Ward et al., 2000).

Antisocial behavior, especially aggression and impulsive behavior, is associated with dysfunctions in the prefrontal cortex (Anderson et al., 1999b; Blair, 2004; Calzada-Reyes et al., 2013; Calzada-Reyes et al., 2016; Krämer et al., 2009; Raine, 1993; Raine et al., 2000). Of special importance are the impairments in the Ventromedial Prefrontal Cortex (vmPFC), which is associated with emotion regulation and moral decision-making, and the Dorsolateral Prefrontal Cortex (DLPFC), which is associated to disinhibition and impulsivity. Both brain structures are associated with aggression and violent behavior (Blair et al., 2006; Giancola, 2004; Hoaken et al., 2003; Morgan and Lillienfield, 2000). For instance, a meta-analysis conducted by Yang and Raine (2009) of 43 neuro-imaging studies showed that impairments of the DLPFC are related to antisocial behavior. Additionally, several studies have shown that an impairment in prefrontal cortex areas lead to the emergence of aggression in different situations, induce psychopathic like traits such as blunted emotions and a lack of empathy (Damasio, 1994), impaired perspective taking with and increased egocentrism and rigidity (Anderson et al., 1999b; Price et al., 1990), and diminished moral judgment (Koenings et al., 2007).

The vmPFC appears to play a crucial role in both aggressive behavior and other antisocial behavior and empathy (Anderson et al., 2006; Blair, 2001; Zheng et al., 2016). Moreover, it is found that one of the most substantial causes of aggressive behavior on a biological level, are lesions in the frontal lobe of the brain (Tateno et al., 2003). For instance, a study of Grafman et al. (1996) showed that war veterans with lesions in the vmPFC exhibited increased aggressive behavior compared to individuals with no lesion. Bufkin and Luttrell (2005) demonstrate that vmPFC dysfunctions can differentiate between violent and nonviolent offenders. In addition, Coccaro et al. (2007) found that patients with explosive disorder showed reduced activity of the vmPFC and vmPFC-amygdala connectivity when they had to watch angry faces. A study of Anderson et al. (1999b) demonstrated that lesions in prefrontal cortex in the first 16 months of an individual can lead to psychopathic antisocial traits and impaired reasoning on a social and moral level. Another study (Chester et al., 2017) demonstrated that physical aggression was associated with reduced gray matter volume in the vmPFC. The patients with less gray matter density in the vmPFC cluster were much more likely to engage in real-world violence. Furthermore, studies using functional Magnetic Resonance Imaging (fMRI) in combination with tDCS have demonstrated that active tDCS stimulation led to increased vmPFC activity during the processing of unfair offers, increased acceptance rates of unfair offers, and an increase in self-reported anger. They also found a decrease in subsequent aggressive behavior following active tDCS stimulation in the first session (Gilam et al., 2018). Other studies using function neuroimaging (i.e. fMRI) demonstrated that increased neuronal activity of the vmPFC predicts increased empathic abilities (Mathur et al., 2010; Waytz et al., 2012).

In sum, the above-mentioned findings support a causal link between vmPFC functionality, empathy and violent behavior, supporting the role of the vmPFC in anger regulation, and providing a promising avenue for reducing aggressive behavior using neuromodulation devices.

Recent insights, such as the notion that the modulation of neuronal firing in specific brain networks can improve the functioning of an individual, has led to the development of techniques to modulate the brain. One of the most feasible devices for non-invasive brain modulation is Transcranial Direct Current Stimulation (tDCS). tDCS delivers low-intensity, direct current stimulation via scalp electrodes. tDCS involves two or more rubber (or metal) electrodes that are placed on the scalp and delivers a weak electric, direct current (1–2 mA) applied transcranially (Nitsche and Paulus, 2000). Recently, studies have shown that the stimulation effect is based on the strength and duration of the current (Batsikadze et al., 2013; Nissim et al., 2019; Samani et al., 2013), whereas before scientist thought that through anodal stimulation, certain brain areas could be stimulated to enhance cortical excitability. On the other hand, it was thought that cathodal stimulation would decrease the activity of the modulated brain region (Nitsche and Paulus, 2000). tDCS functions through the use of a sub threshold modulation of the membrane potentials of neurons, by altering cortical excitability (Nitsche et al., 2003; Nitsche and Paulus, 2000), and can change neuronal synaptic plasticity (Brunoni et al., 2012). This change in neuronal synaptic plasticity is thought to produce Long Term Potentation (LTP)-like ‘learning’ in the neurons that are modulated. Multiple studies confirm that tDCS is indeed an effective intervention to modify brain activity (Barr et al., 2008; George and Aston-Jones, 2010; Jansen et al., 2013). Therefore, tDCS has been investigated as a new treatment for many different psychiatric disorders (Kuo et al., 2017), including schizophrenia (Brunelin et al., 2012), major depression (Kalu et al., 2012), and addiction (Trojak et al., 2017). Although, as described above, an increasing number of studies are published on the effectiveness of tDCS as a treatment intervention for different psychiatric disorders, there are few studies on the effectiveness of increasing empathic abilities and reducing violent behavior in forensic violent offenders. Therefore, the aim of the current review is to evaluate the effectiveness of tDCS an intervention to increase empathic abilities and reduce violent behavior. By doing this, more insight in the effectiveness of tDCS in forensic patients can be established. Subsequently, this new knowledge could be used for the development of new neuromodulation (e.g. tDCS) protocols for interventions in violent forensic populations.

2. Materials and methods

2.1. Overview

A comprehensive literature search was conducted using the databases Google Scholar and PubMed. In addition, articles were searched through the online library of the Erasmus University and Research gate. Articles selected from peer-reviewed academic journals were included. A combination of search terms was used to find articles for this current review, including: tDCS, empathy or empathic abilities, aggression or violent behavior, vmPFC, DLPFC. Additional references were identified using the “related citations” function of PubMed and by reviewing the reference lists of obtained articles. Only studies which primary outcome related to tDCS and the modulation of empathic abilities or antisocial behavior were selected. Articles were selected based on the abstract. 115 articles were selected to use in this review based on their relevance. 28 articles were selected to investigate tDCS to modulate empathic abilities (14) and antisocial behavior (14).

2.2. Studies using tDCS to modulate empathic abilities

Fourteen studies were selected to describe the findings of tDCS and empathic abilities. Of the studies that used tDCS to increase empathic abilities the following locations were picked as a anode position: three studies used the vmPFC, one study used the right Ventrolateral Prefrontal Cortex (rVLPFC), one study used the Dorsomedial Prefrontal Cortex (DMPFC), four studies used the DLPFC either left (2) or right (2), two studies used the LPFC both right and left, another study used anodal tDCS on the right Temporo-Parietal Junction (rTPJ) and one study used the left orbit as a target location. The cathode electrode position was found to be contralateral on the other side of the head most of the times. The current strength was either 1 mA (1), 1,5 mA (4) or 2 mA (8), one study did not indicate the current strength. The stimulation duration and frequency differed between single sessions with a range between 5 till 30 min. One study used a multiple tDCS session protocol of a twenty-minute stimulation session each day consecutive for five days.

2.3. Studies using tDCS to modulate antisocial behavior

Fourteen studies were selected to describe the studies using tDCS to modulate antisocial behavior. Antisocial behavior is divided in aggression (7), risk-taking (6) and inhibition (1). The anodal location of the tDCS is as follows: two studies used the vmPFC, four studies targeted the right VLPFC, four studies targeted the right DLPFC, four studies used bilateral DLPFC. The cathode position was either placed contralateral on the other side of the area (6), contralateral supraorbital (2), occipital (1) or above the left eyebrow (1), or left cheek (1). The current strength was either 1,5 mA (4) or 2 mA (10). The stimulation duration and frequency differed between single sessions ranging between 12 and 20 min. One study had two sessions a day for five consecutive days, one study used three sessions on consecutive days and one study used three sessions with one week in between.

3. Results

Empathic abilities are motivating pro-social behaviors, such as caring for others, inhibiting aggression, and contribute to morality (Batson, 2012). Both empathic concern and moral reasoning are found to be associated with functioning of the vmPFC. This brain area is connected with emotional systems in the brainstem, amygdala, and hypothalamus and links conceptual moral judgment with emotional processes (Decety and Cowell, 2014). An overview of the studies using tDCS to modulate empathic abilities included in this review paper can be found in Table 1, all studies mentioned in Table 1 use a healthy population sample.

3.1. tDCS and empathic abilities

Decades of research have indicated that empathic abilities play a principal role in pro-social behavior, but previous research has mainly focused on the understanding of other's internal state and the perception of other's pain (i.e. pain empathy) (Davidov et al., 2013; Patil and Silani, 2014; Smith et al., 2014; Svetlova et al., 2010; Williams et al., 2014). Few studies have examined modulation of empathic abilities using brain modulation techniques such as tDCS. An interesting study by Balconi and Bortolotti (2012) indicated that stimulating the frontal sensory motor cortex caused individuals to empathize less with the other subjects. Another study (Zheng et al., 2016) reported an increase in altruistic preference and trustworthiness after tDCS targeting the vmPFC. In addition, Sellaro et al. (2016) showed that modulating the DLPFC with tDCS could enhance social cognition.

3.1.1. Moral judgment

Morality is defined as principles and values of how individuals should treat one another and involves concepts such as justice, fairness and rights. It contributes to the norm of social interaction and making the right decisions. It is found that the reinforcement of moral behavior can decrease criminal behavior and increase empathic abilities (Decety and Cowell, 2014; Joyce, 2006). Furthermore, a study of Dubljevic and Racine (2017) demonstrated that damage of the vmPFC was associated with choosing the 'utilitarian' options in the moral dilemmas. This utilitarian decision-making is found to be associated with antisocial and psychopathic traits (Bartels and Pizarro, 2011; Koenings et al., 2007; Koenings et al., 2012). Another study of Kuehne et al. (2015) showed that moral decision-making is not a permanent individual trait but can be manipulated, by showing that tDCS over the left DLPFC changed moral judgments to more non-utilitarian actions.

Darby and Pascual-Leone (2017) conducted multiple studies that have shown that the DLPFC can be stimulated through tDCS to enhance moral judgment. In addition, the study of Fumagalli et al. (2010) demonstrated that stimulating the ventral prefrontal cortex (VPC) showed an increase in utilitarian responses and cathodal stimulation showed a reduction, but only in females. Maréchal et al. (2017) investigated the morality in honest decisions and showed that honesty can be increased with tDCS over the DLPFC, and cheating can be significantly decreased.

3.1.2. Norm compliance

Other studies have provided evidence that anodal tDCS over the right LPFC and the DLPFC leads to more social norm compliance (Kadosh, 2015; Ruff et al., 2013). On the contrary, a study of Gross et al. (2018) showed that cathodal tDCS on the left PFC increased individuals rule-following whereas anodal tDCS led individuals to violate more rules. In addition, Ruff et al. (2013) reported that stimulating the left PFC with tDCS can enhance voluntary and sanction-induced social norm compliance, which can be of major importance not only on a social level, but also to decrease criminal activity (Raine and Yang, 2006). Furthermore, Knoch et al. (2008) reported that cathodal tDCS over the right PFC leads to reduced propensity to punish unfair behavior.

3.1.3. Self-perception

With respect to self-perception, the study from Rêgo et al. (2015) showed that anodal tDCS of the DLPFC reduced hostility, sadness and self-pain perception. Badran et al. (2017) showed that tDCS in combination with mindfulness meditation increased mood and mindfulness, effects that lasted even after eight weeks. Of particular importance for empathy, is the self-construal concept (i.e. the way individuals perceive the self relative to others). Martin et al. (2017) proved that anodal tDCS increased the salience of others, integrating information more towards the 'other' then to the 'self'. Another study (Santiesteban et al., 2012) showed that anodal tDCS on the right TPJ enhanced social ability, by increasing the self-other awareness. Riva et al. (2015) tested anodal tDCS on the vlPFC in social excluded patients and found a decrease in feelings of hurt and social pain after treatment. Furthermore, a combined tDCS/fMRI study conducted by Abend et al. (2018) demonstrated that tDCS can facilitate the activation of the vmPFC to regulate emotion, resulting in a decrease in the intensity of negative valenced clips with anodal tDCS on the mPFC.

3.1.4. Pain empathy

Boggio et al. (2008) showed that anodal tDCS targeting the DLPFC reduced the feelings of discomfort and pain while watching images. In addition, the study of Wang et al. (2016) replicated earlier studies (Boggio et al., 2008; Santiesteban et al., 2012) and found that anodal tDCS over the left DLPFC enhanced empathy for pain. Furthermore, contrary to increasing empathy, inhibiting the frontal sensory motor cortex makes subjects less empathic with others (Hetú et al., 2012). In addition, Coll et al. (2017) showed that cathodal tDCS over the right temporo-parietal junction led to subjects perceiving others pain as less intense, and reported a decrease in event-related potentials (ERP) when participants were watching facial expressions of pain. Furthermore, a study by Feeser et al. (2014) showed that anodal tDCS over the DLPFC increased cognitive control, leading to the reappraisal of negative emotions in relation to empathy for pain.

3.2. tDCS and antisocial behavior

Different neural substrates have been identified that are related to impulsive, antisocial and aggressive behavior in adolescents (White et al., 2013), healthy adults (Krämer et al., 2007; Krämer et al., 2011; Lotze et al., 2007) and psychopathic individuals (Veit et al., 2010). These substrates include brain regions within the prefrontal cortex, cingulate cortex, insular cortex, striatal areas and the amygdala (White et al., 2013; Krämer et al., 2007; Krämer et al., 2011; Lotze et al., 2007; Veit et al., 2010). An overview of the studies that use tDCS to modulate antisocial behavior can be found in Table 2. The study of Molero-Chamizo et al. (2019) used a prisoner sample, and the study of Gilmore

Table 1
Studies using tDCS to modulate empathic abilities. Anode = excitatory, Cathode = Inhibitory, ERP = Event-Related Potential, DLPFC = Dorsolateral PFC, vmPFC = Ventromedial PFC, dmPFC = Dorsomedial PFC, VLPFC = Ventrolateral PFC, LPFC = Lateral PFC.

Study	Emotional concept	Anode electrode position	Cathode electrode position	Current strength (mA)	Duration, number & frequency	Sample size & design	Outcome
Maréchal et al. (2017)	Social norm	Right DLPFC	Left DLPFC	1,5	30 min, single session	145	Cheating decreased after tDCS and an increase in honesty
Ruff et al. (2013)	Norm compliance	Right LPFC	Left LPFC	N.A.	N.A.	59	tDCS right LPFC can enhance voluntary and sanction induced social norm compliance
Gross et al. (2018)	Pro-social behavior	Right LPFC/left LPFC	Left LPFC/Right LPFC	2	30 min, single session	103	Stimulating right LPFC led to increase in less sensitive consequences in light of internal goals and outcomes
Kuehne et al. (2015)	Moral judgment	Left DLPFC	Right parietal cortex	2	20 min, 5 days of 1 session	24	Shifted participants' preference towards non-utilitarian actions influencing moral decision-making.
Rêgo et al. (2015)	Pain empathy	Right DLPFC	Left DLPFC	2	5 min, single session	24	Decrease of hostility, sadness & self-pain perception
Martin et al. (2017)	Salience others	DMPFC	DMPFC	1	20 min, single session	40	Increased salience of others, integrating info more to the 'other' then the 'self'
Riva et al. (2015)	Social pain	Right VLPFC	Left supra-orbital area	2	20 min, single session	80	Less social pain and feelings of hurt
Knoch et al. (2008)	Moral judgment	Left Orbit	Right DLPFC	1,5	13 min, single session	64	Cathodal tDCS on right DLPFC reduces pt. propensity to punish unfair behavior
Wang et al. (2014)	Pain empathy	Left DLPFC	Left DLPFC	2	5 min, single session	27	Increase of pain empathy after anodal tDCS
Coll et al. (2017)	Pain empathy	Right temporo-parietal junction	Right temporo-parietal junction	2	20 min, single session	48	Cathodal tDCS led to subjects feeling less empathized with the other, feeling their pain as less intense. Decreased ERP to facial expressions of pain
Fumagalli et al. (2010)	Norm compliance	vmpFC	vmPFC/occipital	2	20 min, single session	78	Anodal tDCS increased the utilitarian responses, but only in females
Zheng et al. (2016)	Trust/social norm	vmPFC	vmPFC	2	20 min, single session	60	Altruistic preference + trustworthiness higher after tDCS
Feeser et al. (2014)	Emotion regulation	Right DLPFC	Right supraorbital	1,5	20 min, single session	21	Enhanced cognitive control during emotion regulation
Abend et al. (2018)	Emotion regulation	vmPFC	Back of head	1,5	20 min, single session	19	Reduction of negative emotions

Table 2
Studies using tDCS to modulate externalizing behavior. Anode = Excitatory electrode, Cathode = Inhibitory electrode, DLPFC = Dorsolateral Prefrontal Cortex, VLPFC = Ventrolateral Prefrontal Cortex.

Study	Behavior	Anode electrode position	Cathode electrode position	Current strength (mA)	Duration, number & frequency	Sample size	Outcome
Hortensius et al. (2012)	Behavioral aggression	Left + Right DLPFC	Left + right DLPFC	2	15 min, single session	80	Anodal tDCS on the left DLPFC had an increase in aggressive behavior when angry
Choy et al. (2018)	Behavioral aggression	Left + Right DLPFC	Left + right DLPFC	2	20 min, single session	86	Reduced intentions to commit aggression and enhance perceptions of the moral wrongfulness of the aggressive acts
Dambacher et al. (2015)	Proactive aggression	Right DLPFC	Above left eyebrow	2	12,5 min, single session	32	Reduced proactive aggression in men after anodal tDCS on right DLPFC
Riva et al. (2015)	Behavioral aggression	Right VLPFC	Supraorbital region	1,5 mA	20 min, single session	80	Aggression decreased following social exclusion
Riva et al. (2017)	Unprovoked aggression	Right VLPFC	Supraorbital region	1,5 mA	20 min, single session	80	Reduced unprovoked aggression in violent game-players.
Fecteau, Knoch, et al. (2007)	Risk taking	Right DLPFC	Left DLPFC	2 mA	13 min, single session	36	Bilateral tDCS causes behavioral changes in risk-taking. Decreased risky behavior
Fecteau, Pascual-Leone, et al. (2007)	Risk taking	Right DLPFC	Left DLPFC	2 mA	13 min, single session	36	Bilateral tDCS causes behavioral changes in risk-taking. Decreased risky behavior
Gilmore et al. (2017)	Risk taking	Right PFC	Left PFC	2 mA	25 min, 2 times a day 10 sessions total.	30	tDCS of the DLPFC reduced risk-taking behavior in veterans with clinical relevant impulsivity
Kelley et al. (2013)	Anger related rumination	Left/right PFC	Left/right PFC	2	15 min, single session	115	Increase right activation and decrease left cortical activation
Yu et al. (2015)	Inhibition	vmPFC	Left cheek	2	20 min, Single Session	8	Increase in stop efficiency
Chen (2018)	Behavioral aggression	rVLPFC	Oz (occipital)	2	Single session	32	Decrease in proactive and reactive aggression
Molero-Chamizo et al. (2019)	Self-reported aggression	Left/Right DLPFC	Contralateral supraorbital ridges	1.5	15 min, 3 sessions in 3 consecutive days	41	Decrease in aggressiveness
Manuel et al. (2019)	Risk-taking	vmPFC	vmPFC	2	20 min, 3 sessions one week apart	20	Anodal tDCS effects delay discounting
Gallucci et al. (2020)	Frustration-aggression	Left/right VLPFC	Contralateral supraorbital areas	1.5	20 min, Single session	90	Left anodal tDCS increased aggression and gender difference

et al. (2017) used veterans with clinically relevant impulsivity but the rest of the studies tested healthy adults.

3.2.1. Aggressive behavior

Several previous studies have shown that the PFC inhibits aggressive behavior (Anderson et al., 1999b; Blair and Cipolotti, 2000; Halasz et al., 2006; Lotze et al., 2007; Raine et al., 1997; Raine et al., 1998). The study of Molero-Chamizo et al. (2019) demonstrated that anodal tDCS over the left and right DLPFC reduced self-reported aggression in prisoners. Interestingly, the work of Peterson et al. (2008) showed that increased activation in the left PFC rather than the right PFC is involved in activating behavioral aggression. Based on earlier findings (Hortensius et al., 2012; Peterson et al., 2008) that anodal tDCS applied on the left DLPFC seems to increase aggressive behavior, Dambacher et al. (2015) used anodal tDCS over the right DLPFC to induce the right frontal hemispheric dominance and found significant results in decreasing proactive aggression in male individuals. These results support earlier studies (Peterson et al., 2008) that anger-related relative left frontal cortical activation correlates with behavioral aggression. In a similar vein, a study conducted by Juan and Muggleton (2012) showed that cathodal tDCS on the right DLPFC could elevate impulsivity and reduce inhibition. Neuroimaging studies (Aron and Poldrack, 2006; Li et al., 2006; Zandbelt et al., 2013) have provided evidence of a network of regions that together form this 'stopping network' and are involved in inhibitory control. In addition, Yu et al. (2015) demonstrated that especially the vmPFC is activated in the 'stopping network' and anodal tDCS over this region resulted in increased stopping efficiency and inhibitory control. Kelley et al. (2013) successfully manipulated and increase in right frontal cortical activity and with that showed the feasibility of tDCS as a direct manipulator of cortical activity and anger rumination. Gallucci, Riva, Romero Lauro, and Bushman (2020) reported that anodal tDCS on the left VLPFC increased frustration-induced aggression, demonstrating the importance of the location of the modulation but also the importance of VLPFC in aggressive responses. A study of Choy et al. (2018) showed that after anodal tDCS stimulation of the DLPFC, an increase in activity in the prefrontal cortex was associated with a reduction in intentions to commit aggression and enhanced perceptions of the moral wrongfulness of the aggressive acts. Furthermore, the study of Chen (2018) used anodal tDCS on the right VLPFC and showed reduced proactive and reactive aggression.

3.2.2. Social exclusion and related aggressive behavior

Riva et al. (2015) showed in their study the important relationship between social exclusion and aggressive behavior. They reported that tDCS anodal on the right vlPFC reduced the feeling of social exclusion and the aggressive behavior that follows this exclusion. A more recent study (Riva et al., 2017) indicated that anodal tDCS over the right vlPFC could reduce unprovoked aggressive behavior that occurs from playing violent videogames

3.2.3. Risk taking

Risk-taking behavior and risky decision making is found to be linked to an increased vulnerability for externalizing behavior. The review paper of Kuin et al. (2015) demonstrated that multiple studies prove that risky decision-making is associated with aggression, for both reactive as proactive aggression. In addition, previous research shows that inhibiting the DLPFC activity leads to increased risk-taking (Knoch et al., 2006). Other studies (Fecteau, Knoch, et al., 2007; Fecteau, Pascual-Leone, et al., 2007) have reported that anodal tDCS over the DLPFC effectively decreased risk-taking behavior. In addition, the study of Gilmore et al. (2017) showed that tDCS over the DLPFC reduces risk-taking behavior in veterans with clinically relevant impulsivity with results even after a follow-up of two months. Bechara et al. (1994, 1996, 1997) have collected substantial evidence over the past several years that patients with bilateral lesions of the vmPFC cannot predict positive or negative consequences of their actions but instead immediately available rewards and punishments influence the behavior of these patients (Bechara et al., 1994). It was found that the patients with the vmPFC lesions, compared to healthy controls, failed to display anticipatory electrodermal responses when confronted by a risky choice. The healthy controls generated such electrodermal responses even prior to explicitly knowing it was a risky choice (Bechara et al., 1996; Bechara et al., 1997). Furthermore, in the study of Manuel et al. (2019) they found that anodal stimulation of the vmPFC affected delay discounting for emotions and reward, whereas cathodal stimulation of the vmPFC increased impulsivity. These findings support the important association between the vmPFC and risky decision-making.

4. Discussion

This literature review was conducted to investigate whether tDCS could be an effective tool for a new intervention to increase empathic abilities and decrease violent behavior in forensic populations. Empathy is crucial for social relationships, meaning that a deficit in empathic ability could lead to antisocial and deviant behavior, and with that, a higher risk of violence (Preller et al., 2014). The reviewed studies showed some evidence that empathic abilities can be increased with anodal tDCS over the PFC. These studies mainly focused on the DLPFC as target region (Darby & Pascual-Leone, 2017; Kadosh, 2015; Knoch et al., 2008; Kuehne et al., 2015; Maréchal et al., 2017; Sellaro et al., 2016), in which anodal stimulation was found to increase empathic abilities Other studies (Abend et al., 2018; Fumagalli and Priori, 2012; Riva et al., 2015; Zheng et al., 2016) targeted the vmPFC with anodal tDCS and also showed an increase in empathic abilities. Additionally, in some studies, other regions of the brain were also successfully targeted. For example, studies have shown that anodal tDCS on the TPJ were effective when metalizing abilities were concerned (Coll et al., 2017; Santiesteban et al., 2012). These results confirm the importance of the DLPFC and vmPFC in regulating (pain) empathy, moral judgment, self-perception and norm compliance. All in all, these findings provide a starting point for the use of tDCS as an intervention to increase empathic abilities in forensic and patient populations.

This review also investigated the effect of tDCS on aggression and antisocial behavior. The reviewed literature showed that tDCS can modulate aggressive and violent behavior, with studies mainly targeting the DLPFC because of its involvement in cognitive and inhibitory control. Overall, results showed that anodal stimulation over the DLPFC results in a decrease in impulsivity and aggression. Furthermore, other studies have demonstrated the importance of vmPFC as a target region in reducing aggression (Chen, 2018; Yu et al., 2015) and decreasing risk-taking behavior (Bechara et al., 1994, 1996, 1997; Manuel et al., 2019). But effectiveness of other regions, such as targeting the vlPFC to decrease social exclusion related to aggression is also found (Gallucci et al., 2020; Riva et al., 2015, 2017).

In sum, this review confirms the importance of the DLPFC and vmPFC in regulating antisocial behavior. The studies provide evidence for the usefulness of tDCS as an intervention to decrease aggression in individuals, to reduce the feeling of social exclusion and associated aggression, and to reduce risk-taking behavior.

Although the majority of studies using tDCS targeted the DLPFC, the current findings also support the importance of the vmPFC as a target region of interest for increasing empathic abilities and reducing aggression. That is, this review showed that the vmPFC is a key region in theories on empathy and aggression (refs…) and these theories are supported by the different tDCS studies that showed that targeting the vmPFC results in the modulation of various processes, including valued based learning, emotional decision-making and empathic abilities (Anderson et al., 2006; Damasio, 1994; Hiser and Koenigs, 2018; Janowski et al., 2013; Mathur et al., 2010; Waytz et al., 2012; Zheng et al., 2016).

Although the previously mentioned studies indicate that tDCS could be a promising intervention to increase empathic abilities and reduce antisocial behavior, results still vary on different parameters. Variations in intensity, duration, electrode positions, target location and session repetition timing could explain the inconsistent results found in tDCS trials in pathological conditions (Lefaucheur et al., 2017), but also in healthy populations. These factors should be taken into consideration when designing stimulation protocols and interpreting the effects of tDCS when applied as an intervention for psychiatric disorders. For instance, a study of Mancuso et al. (2016) showed that tDCS is most effective after multiple sessions, while in the reviewed studies that modulate empathic abilities, all of the studies use a single session of tDCS, except for the study from Kuehne et al. (2015). In addition, some studies find an opposite effect when using tDCS on different hemispheres. For example, in the study by Gross et al. (2018) it was found that cathodal tDCS increased the rule-following of the participants, but on the contrary when applying anodal tDCS, the participants showed an increase in violating the rules. Modulating the right LPFC in this study did not resulted in the expected effects in regard to increasing or decreasing selfishness, but showed more evidence in to the role of the LPFC. With regard to the electrode positions, the electrode montage is found to be a key factor to determine where the current will go (Biksom et al., 2012). However, we found that this position differs a lot throughout the reviewed papers, resulting in differences in current flow and thereby effectivity of the tDCS.

Also, even though researchers have increasingly examined the advantages of using tDCS as an intervention procedure, thereby adding to the knowledge about neuromodulation, the precise neurobiological mechanisms underlying tDCS remain insufficiently understood (Chrysikou et al., 2017). Replicating studies and the reported findings has demonstrated different results, and the specification of the precise conditions to use tDCS is still a concern in the field (Mancuso et al., 2016).

Overall, there is a great deal of variability in the outcomes that may be largely attributed to small and heterogeneous sample sizes, diversity across laboratories and countries, target locations and duration of the sessions. These limitations are intensified by the lack of understanding of the precise effects of a given tDCS protocol on the brain over different durations and cognitive tasks.

5. Conclusions

The current review showed that, although most studies examining the use of tDCS to increase empathic abilities and decrease antisocial behavior have targeted the DLPFC, research also supports the vmPFC as promising target for such modulation effects. Evaluating these results in light of theory concerning the role of the vmPFC in empathy and antisocial behavior (i.e. Blair, 2001, 2005; Blair et al., 2006), further supports the vmPFC as a target for intervention in forensic populations. However, future research on the vast parameter space of tDCS (e.g. stimulation intensity, electrode location, polarity) is needed to consolidate tDCS as a tool in forensic science. To be able to examine whether tDCS is indeed an effective treatment intervention in forensic populations, future research not only has to take the above variables into account, but also should focus not only on the effectiveness of tDCS on overt treatment outcome, but also on the long-lasting effects of tDCS on brain functionality (e.g. functional connectivity, brain network properties). Using tDCS as a treatment intervention, activity in brain areas such as the vmPFC can be restored so that functionality and connectivity in relevant networks becomes effective again.

As far as we know, currently there is only one study which will examine the effectiveness of tDCS as a treatment intervention in forensic patients in a randomized, sham controlled, and double blind trial using multiple sessions of tDCS (see Sergiou et al., 2020). In that study, they will also look into the effects of the tDCS on electrophysiological dynamics and network properties using EEG.

Declaration of competing interest

None.

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