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Self-generation and positivity effects following transcranial random noise stimulation in medial prefrontal cortex: A reality monitoring task in older adults

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ABSTRACT

Activation of medial Prefrontal Cortex (mPFC) has been typically found during reality monitoring tasks (i.e., distinguishing between internal self-generated *vs* external information). No study, however, has yet investigated whether transcranial Random Noise Stimulation (tRNS) over the mPFC leads to a reduction in reality-monitoring misattributions in aging. In particular, stimulating mPFC should increase the number of cognitive operations engaged while encoding and this distinctive information may help older adults to discriminate between internal and external sources better. In addition, given that older adults are more sensitive to positively-charged information compared to younger adults and that mPFC is typically recruited during encoding of positive stimuli with reference to themselves, activation of mPFC should further sustain source retrieval in older adults. In this double-blind, sham-controlled study, we examined whether tRNS over the mPFC of healthy younger and older adults during encoding enhances subsequent reality monitoring for seen versus imagined emotionally-charged words. Our findings show that tRNS enhances reality monitoring for positively-charged imagined words in the older adult group alone, highlighting the role that mPFC plays in their memory for positive information. In line with the control-based account of positivity effects, our results add evidence about the neurocognitive processes involved in reality monitoring when older adults face emotionally-charged events.

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1. Introduction

Memories contain information that originate from two different types of sources: external, deriving from perceptual processes, and internal, generated by processes such as reasoning, thought, and imagination. Importantly, memories originating from internal sources such as thoughts are no less "real" than those created by external perceptual experiences and both produce persistent memory traces that can later be used to attribute memories to their origins. Johnson and Raye (1981) call this ability "reality monitoring" and refer to an array of different mental activities (e.g., Johnson, 1992) that, together, allow individuals to attribute memories to an internal versus external source. Johnson and Raye (1981) suggested that people rely on two different mechanisms in order to make source attributions. On the one hand, they can encode the source of the event depending on the primary information carried by the event itself. On the other hand, people can use conscious reflective decision-making processes to determine whether something really happened to them. Moreover, decades of research by Johnson and colleagues (e.g., Johnson & Raye, 1981; Mitchell & Johnson, 2009) have underlined how events in memory that actually occurred are typically accompanied by abundant perceptual and contextual details (e.g., visual, auditory, spatial and temporal details), whereas self-generated events are typically accompanied by more cognitive aspects (e.g., thinking about the event, engaging in mental imagery, etc.). In other words, source information is inferred on the basis of the quantity and quality of the different types of information (e.g., contextual *vs* cognitive details) that are encoded and subsequently available at retrieval. This assumption is also supported by a series of neuroimaging studies (for a review see Mitchell & Johnson, 2009) that highlight how the prefrontal cortex (PFC) is involved in processing or representing the cognitive operations (e.g., the act of imagining) carried out during encoding. This information can later be used when remembering as a cue that the event was self-generated. Differently, activation of posterior visual areas is typically associated with encoding of perceptual events. In this case, visual information is used as a cue of an externally derived event.

Generally speaking, reality monitoring is a crucial ability for everyday living. Reality monitoring processes are involved when, for instance, people try to remember whether they really did something or they just thought of doing it or when they remember whether they actually said something to someone or just imagined saying it. These operations are fundamental for attributing the correct level of reality to events and correct source attributions allow people to avoid errors that range from putting the sugar in a cup of tea twice to imagining that something bad happened. Reality monitoring is, thus, a complex memory ability and we all confuse memories of events that actually happened with events that were only imagined sometimes. Moreover, older adults seem to be particularly impaired when asked to distinguish between perceived and imagined events (e.g., Henkel, Johnson, & De Leonardis, 1998; Mammarella & Cornoldi, 2002).

Interestingly, source monitoring research (e.g., Hashtroudi, Johnson, & Chrosniak, 1990; May, Rahhal, Berry, & Leighton, 2005; Mitchell, Hunt, & Schmitt, 1986; Rahhal, May, & Hasher, 2002; Taconnat & Isingrini, 2004) has identified two conditions that seem to reduce source attribution errors in older adults. First, older adults show increases in their source monitoring performance when asked to distinguish between self-generated information and information of other types (e.g., seen). For example, Hashtroudi et al. (1990) found that older adults had better memory for their own thoughts and feelings than younger adults showing how they rely on self-initiated processes more than on external information as a basis for discriminating between an external and internal source. Second, when older adults are asked to remember valenced (especially positively-charged) self-relevant information versus neutral information, their source memory performance increases. For example, May et al. (2005) found that older adults were impaired compared to younger adults in their ability to recall perceptually based source information (e.g., location or color), but were not impaired in recalling affective, value-based source information. In particular, source-memory deficits were attenuated if source information contained an emotional component that was significant to older adults (e.g., information relevant for their health) rather than a general conceptual component (e.g., information regarding the cost of a product). Because emotional material, especially positively-charged information, is more engaging for older adults, it may evoke more elaborative, detailed self-reference processing that later sustains their source recall.

In this study, we investigated reality-monitoring processes in aging by focusing on these two beneficial conditions, self-generation and valence effects while stimulating with a noninvasive brain stimulation technique. We adopted an affective version of an acoustic reality-monitoring task and stimulated the medial Prefrontal Cortex (mPFC), a key brain region involved in both self-generated processes and in biasing emotion processing towards the positive pole. Here, we will first briefly review studies on the role of mPFC in reality monitoring in terms of self-generation and positivity effects and then describe the stimulation technique that we adopted.

With regards to the role of mPFC during generation, a series of recent neurophysiological studies (e.g., Metzak, Lavigne, & Woodward, 2015) found that mPFC was more active during reality monitoring tasks since these tasks require individuals to compare internal (self) and external (other) source information. In particular, mPFC activation (e.g., Kensinger & Schacter, 2005) has been detected during correct attributions of self-generated information. The principal assumption is that mPFC is mainly involved in processing the cognitive operations engaged while encoding that require internal processes, or generally speaking, reflective demanding processes (e.g., Nolde, Johnson, & D'Esposito, 1998). A complementary assumption is that mPFC modulates encoding resources in mnemonic regions such as the hippocampus in order to maximize efficiency of memory encoding (e.g., Berkers, Klumpers, & Fernández, 2016). This may have an impact on an individual's memory specificity.

Although the initial reality monitoring approach focused on retrieval of source information and emphasized the role of mPFC during monitoring and remembering, subsequent studies by Johnson and colleagues also stressed the importance of mPFC at encoding (see Mammarella & Fairfield,

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2008 for a review). Reality monitoring is dependent on elaboration and organization of studied material and the pattern of functional Magnetic Resonance Imaging (fMRI) activity supports the idea that mPFC is involved in such processes during encoding. In particular, a series of studies found that medial anterior PFC is more active during internal generation of information or when conceptual information is required compared to perceptually derived information such as stimulus size or position on the screen (Dobbins, Foley, Schacter, & Wagner, 2002; Simons, Owen, Fletcher, & Burgess, 2005). In particular, given that reality monitoring accuracy depends on efficient encoding of qualitative features that accompany an event and that mPFC is recruited during processing of cognitive features that typically belong to internal events (such as self-generation, imagination, elaboration, controlled processes, etc., Simons et al., 2005), stimulation of mPFC at encoding should enhance the processing of self-initiated processes that can be used by participants to later attributing an event to an internal source.

Consistent with the idea that medial PFC is involved in processing self-generated information, literature on memory and emotion interaction in aging showed that activity in this area is also related to greater engagement of older adults with positively-charged stimuli. This finding highlights that this area may be especially sensitive to different self-relevant motivational goals (e.g., Mather, 2016).

In particular, older adults are more likely to process emotional information with reference to themselves and to generate valence-specific effects according to their emotion priorities and individual self-relevant goals than younger adults (e.g., Mather & Carstensen, 2005). In fact, a series of studies has shown that older adults focus on positive stimuli more and on negative stimuli less compared to younger adults, a pattern that is now well known as the age-related positivity effect (Mather & Carstensen, 2005). As suggested by Mather (2016), this effect is often associated with age-related differences in mPFC activation for positive versus negative stimuli (see also Addis, Leclerc, Muscatell, & Kensinger, 2010; Leclerc & Kensinger, 2008, 2010). In particular, mPFC can be employed both to engage positive stimuli more deeply and/or to disengage from negative stimuli. In aging individuals activation of mPFC should increase the number of self-relevant cognitive operations (in this case processing of positive information) and sustain older adults in their source attribution.

In summary, several studies show mPFC involvement during self-generated and positive information processing, and indirectly indicate that stimulation of mPFC may improve reality monitoring for emotional information.

With regards to the specific stimulation technique adopted in our study, we used transcranial Random Noise Stimulation (tRNS), a non-invasive, painless electrical stimulation that can be used in experimental psychology studies to investigate the contribution of different brain regions to cognitive processing. tRNS generates a random level of current for every sample passed between 2 electrodes and, like anodal transcranial Direct Current Stimulation (tDCS), seems to improve performance during cognitive tasks, presumably by increasing cortical excitability (e.g., Terney, Chaieb, Moliadze, Antal, & Paulus, 2008; van Koningsbruggen, Ficarella, Battelli, & Hickey, 2016; Popescu et al., 2016 for a short review).

In this study, we chose to adopt tRNS instead of tDCS because tRNS has been shown to produce stronger effects than anodal tDCS (Fertonani, Pirulli, & Miniussi, 2011; Herpich et al., 2015; Romanska, Rezlescu, Susilo, Duchaine, & Banissy, 2015; but see Mulquiney, Hoy, Daskalakis, & Fitzgerald, 2011 for opposite results) since repeated stimulation at random noise hinders the homeostasis system to a greater extent than does tDCS. In addition, tRNS has been shown to yield stronger long-term benefits of brain stimulation (e.g., Paulus, 2011).

We chose to stimulate mPFC at encoding since increasing cortical activity in mPFC region may better highlight the role of mPFC during processing of reflective demanding operations that may be later used as a cue to attribute a mental experience to an internal source. In addition, by stimulating this region, we speculated that we may find an increase rather than a decrease of cognitive resources in line with the Mather and Knight's (2005) control-based account of positivity effects in memory of older adults. Finally, we aimed to discriminate conditions that may reduce rather than increase source misattributions in aging.

Although older adults make a larger number of source misattributions compared to younger adults (e.g., Henkel et al., 1998; Mammarella & Cornoldi, 2002), no study, as far as we know, has explored whether tRNS over the mPFC may enhance reality monitoring via self-generation and positivity effects in older adults. That is, no study investigated whether activation of mPFC makes internal events richer in cognitive operations (both in terms of imagination and emotional elaboration) and thus provides older adults with relevant information for attributing the event to the self.

Consequently, our aim in this study is to clarify self-generation and valence effects on age-related differences in mPFC functioning during an acoustic reality-monitoring task. In particular, we examined whether age-related differences during the encoding of seen versus imagined emotionally-charged words relates to the magnitude of the self-generated and positivity effects in the mPFC. Although findings regarding the mPFC are fairly consistent when dealing with self-generation effects (e.g., Gutchess, Kensinger, & Schacter, 2007; Mano et al., 2011), the directionality of the age-related mPFC changes during emotion processing (e.g., whether this is an over-recruitment of mPFC while processing positive stimuli alone) is less clear. The present study was also designed to further assess whether older adults engage prefrontal resources in order to increase positivity.

Our assumptions were as follows. First, if self-generation and positivity effects are mediated by an increase in the recruitment of cognitive resources or more reflective demanding processes with respect to other encoding conditions and older adults are able to focus on and use these types of source details to aid source attribution, we expect source attribution for positive words that were imagined to be a particularly informative condition. Following random noise stimulation over the mPFC, we thus predict that reality-monitoring performance should increase in older adults especially when attributing positive words to an imagined source relative to other types of source information. Second, if mPFC activity increases more with positive stimuli at encoding, stimulation should lead to a reduction of the negativity bias typically found in younger adults. In summary, we expect older adults to show an increase in source memory for imagined positive items only under stimulation. That is, older adults should show better source memory in conditions that activate the mPFC and make encoding more distinctive in terms of greater involvement of reflective demanding processes (such as imagination and a focus on positive information).

2. Material and methods

2.1. *Participants*

The participants were 48 healthy younger adults (24 women) between 19 and 25 years of age and 48 healthy older adults (24 women) between 61 and 80 years of age (see Table 1 for participant characteristics). All participants were right handed, native Italian speakers and reported normal or corrected-to-normal vision. Auditory acuity was evaluated using a screening procedure developed by Reilly, Troiani, Grossman, and Wingfield (2007). We randomly assigned one-half of the younger and older participants to the active stimulation group and the other half to the sham stimulation group in a double-blind design.

All participants completed the forward and backward digit spans of the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981) and the Phonemic Fluency task from Mondini, Mapelli, Vestri, Arcara, and Bisiacchi (2011). The Positive and Negative Affective Schedule (PANAS, Watson, Clark, & Tellegen, 1988) was administered to assess current mood. Older adults also completed the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) and the Geriatric Depression Scale (GDS, Yesavage et al., 1982). All older participants scored at least 27 on the Mini Mental Status Examination (Folstein et al., 1975). Younger and older adults were comparable across stimulation conditions for gender and cognitive performance, PANAS and years of education as determined by individual independent-samples *t*-tests with $\alpha = .05$. There were no significant differences in gender, cognitive performance, PANAS or years of education between younger and older adults.

In addition, there were no significant differences in terms of cognitive performance, PANAS or years of education between the stimulation and sham group in both the younger and the older adults group.

Table 1 – Participant characteristics by age group.

Characteristic	Younger	Older
	M (SD)	*M (SD)*
Age (in years)	22.6 (2.1)	69.8 (4.5)*
Sex	24 M, 24 F	24 M, 24 F
Education (in years)	14.1 (1.9)	13.6 (3.5)
MMSE		28.4 (1.4)
GDS		6.9 (3.4)
Verbal fluency	12.44 (2.9)	11.96 (2.6)
Digit span forward	7.6 (1.6)	7.1 (1.9)
Digit span backward	6.6 (1.6)	6.2 (1.3)
PANAS positive	32.8 (6.1)	33.6 (6.4)
PANAS negative	22.4 (7.2)	21.8 (7.6)

*$p < .001$.

Exclusion criteria included history of traumatic brain injury, epilepsy, developmental disorder, diagnosable current substance abuse dependence or other known neurological condition. We also excluded participants if clinical and/or research records confirmed clinically significant depression with no history of depression or other psychiatric or neurological disorder.

All participants gave written informed consent prior to participation and the study was approved by the Departmental Ethic Committee. Participants did not receive compensation for their participation.

2.2. *Materials*

A total of 108 words were selected from the Italian adaptation of the Affective Norms for English Words (Montefinese, Ambrosini, Fairfield, & Mammarella, 2014). As for the English version, the Italian ANEW provides a set of normative emotional ratings for a large number of words in the Italian language in terms of pleasure, arousal etc. Moreover, the Italian version also provides other psycholinguist indexes such as familiarity, imaginability and frequency. Positive words had a mean valence of 8.26 (.19), arousal of 6.12 (.94), familiarity of 7.25 (.78) and imaginability of 7.42 (.98). Negative words had a mean valence of 1.74 (.25), arousal of 6.54 (.78), familiarity of 6.76 (1.23) and imaginability of 7.00 (.96). Neutral words had a mean valence of 4.71 (.20), arousal of 5.08 (.38), familiarity of 7.06 (.82) and imaginability of 7.47 (.98). Independent *t*-tests showed that positive and negative words differed for valence but were matched for arousal, familiarity, and imaginability. Neutral words were different for arousal and valence but matched positive and negative words for familiarity, and imaginability. Words were recorded by a male speaker and presented to participants through a pair of Bose headphones. Volume was adjusted to individual preference before beginning the experimental session. The study phase included 72 words (24 positive, 24 negative, and 24 neutral). Half of the positive words (12 items) were assigned to the seen condition and the remaining half to the imagined condition (12 items). The same attribution was repeated for negative and neutral words. Items from each valence and from each study condition (seen or imagined) were pseudorandomly intermixed. In addition, no more than five items of the same valence or study condition occurred consecutively. Old (e.g., a word that was presented in the seen or imagined condition) and new (a never studied word) items were counterbalanced across participants. Five filler items with the same psycholinguistic characteristics of the experimental items were presented at the beginning of the list and five at the end to reduce primacy and recency effects.

2.3. *Procedure and apparatus*

The experimental procedure was similar to the one adopted by Kensinger, O'Brien, Swanberg, Garoff-Eaton, and Schacter (2007) and consisted in a study phase followed by an unexpected reality-monitoring task. The experimental timeline is shown in Fig. 1. Before beginning the experiment, participants

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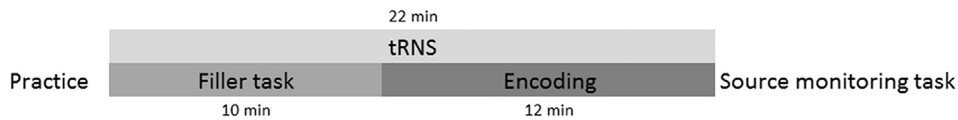

Fig. 1 – Time-line of the experiment.

gave written informed consent, were screened for cognitive abilities, and provided demographic and handedness information via paper questionnaires. The reality-monitoring task was presented using E-Prime software (Psychology Software Tools, Inc., 2012).

The auditory presentation of each word was immediately followed by either a visual presentation of the same word (seen condition) or a fixation cross (imagined condition). In the seen condition, words were presented in black lower case letters on a white screen. In the imagine condition, a black fixation cross appeared in the center of the screen and participants were instructed to imagine the written form of the word. The word or fixation cross remained on the screen for 6000 msec during which participants completed a letter-height decision task in which they were instructed to indicate whether the first letter of each word was shorter than the last letter (if yes, participants pressed the key 1; if no, they pressed 0). Before beginning the study phase, participants were given an overview of the cognitive task, instructions for the encoding session and completed a practice session that included 10 practice words to familiarize with the letter-height decision task.

The electrodes were positioned on the participant immediately after completing the practice trials. tRNS or sham stimulation lasted about 22 min. During the first 10 min, participants completed a visuo-spatial filler task. During the successive 12 min, participants listened to a series of words, studied or imagined the words and made letter-height decisions. As soon as stimulation ceased, participants were presented with an immediate unexpected reality-monitoring task. Finally, electrodes were removed and participants were dismissed.

Learning was incidental so participants did not know that a memory test for source information would follow. We chose incidental learning because this type of learning generally lowers memory performance compared to an intentional study condition and, consequently, better highlight the contribution of stimulation in our reality-monitoring task.

2.4. *tRNS data acquisition*

As done in previous studies (e.g., Pasqualotto, 2016; Popescu et al., 2016), a double-blind procedure was adopted. Participants did not know whether they were stimulated or not and a third party researcher was in charge of running the experiment. tRNS was delivered using a BrainSTIM device (EMS, Italy) through two 5 × 5 cm electrodes inserted into saline-soaked synthetic sponges. Stimulation consisted of high frequency noise (100–600 Hz) with an intensity of 1 mA. The tRNS group was stimulated for a total of 22-min with increasing/decreasing 'ramps' of 60 sec at the beginning and at the end. The sham group also had electrodes on their heads for 22 min, but stimulation lasted only 20 sec. More specifically, we placed one electrode on the frontal pole with reference to halfway between Fp1 and Fp2 and the glabella (International 10–20 system). We positioned the second electrode in the Oz area. We introduced a positive direct current (DC) offset (.5 mA) to the stimulation in order to produce a polarity-specific randomly oscillating current on the mPFC which mirrors the effects of tDCS. Participants in the sham group received a 'placebo stimulation'.

2.5. *Data analyses*

Our primary measure of interest was participants' ability to correctly attribute a word to its corresponding source (e.g., Kensinger et al., 2007; Mammarella & Cornoldi, 2002). In particular, we conducted analyses to examine how stimulation (thought to increase self-generation and valence processing) affects the ability to correctly remember whether a word had been seen or imagined at study. We computed conditionalized source monitoring scores for seen and imagined items. These scores were calculated by dividing the proportion of correctly attributed seen or imagined items by the general recognition score for the seen or imagined items (i.e., for seen items: S/S divided by S/S + I/S). These scores index participants' ability to correctly identify an item as seen or imagined given that they recognize that the item has been studied.

In addition, we also conducted analyses on recognition memory scores computed as HITs-FA to test whether stimulation affects the ability to remember whether an item was encountered before independently of source information. These scores derived from collapsing "seen" and "imagined" responses (not "new") to seen items and collapsing "seen" and "imagined" (not "new") responses to imagined items. Hit scores, thus, included both correct and incorrect source attributions for old items. Discrimination was also analyzed using d' to obtain response biases such as C measures. In particular, we reported analyses on C scores. Positive values of C indicate a conservative response bias, negative values indicate a liberal response bias, and 0 indicates a neutral bias.

3. Results

Accuracy on the letter-height decision task was high. All participants scored above 90%. An analysis with Age (younger adults, older adults) and Stimulation (random noise *vs* sham) did not reveal any main effects or interaction (all $F < 1$).

Source memory. We conducted an analysis of variance (ANOVA) with Valence (positive, negative, neutral) and Type of Source (seen, imagined) as within participants factors and Age (younger adults, older adults) and Stimulation (random noise *vs* sham) as a between-participants factor. Results are presented in Table 2. The ANOVA revealed a significant effect

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Table 2 – Conditionalized mean (SE) source memory proportions of Seen and Imagined as a function of Stimulation, Valence, Age and Type of source.

Stimulation	Age	Valence	Source	
			Seen	Imagined
tRNS	Younger	Positive	.45 (.04)	.61 (.04)
		Negative	.40 (.03)	.55 (.04)
		Neutral	.38 (.06)	.59 (.05)
	Older	Positive	.54 (.06)	.76 (.03)
		Negative	.33 (.02)	.49 (.05)
		Neutral	.32 (.04)	.48 (.06)
SHAM	Younger	Positive	.45 (.02)	.55 (.05)
		Negative	.46 (.02)	.68 (.03)
		Neutral	.37 (.04)	.51 (.03)
	Older	Positive	.37 (.03)	.51 (.08)
		Negative	.31 (.03)	.46 (.04)
		Neutral	.30 (.03)	.40 (.04)

of Age, $F(1,92) = 9.73$, $p < .01$ 41.89, $\eta^2 = .09$ since younger adults (.51) performed better than older adults (.44). There was a significant effect of Stimulation, $F(1,92) = 4.69$, $p < .05$, $\eta^2 = .05$ as random noise stimulation (.50) led to better source monitoring performance compared to sham (.45). There was a significant effect of Type of Source, $F(1,92) = 29.76$, $p < .001$, $\eta^2 = .24$ as imagined words were attributed better (.55) than seen words (.39). There was a significant effect of Valence, $F(2,184) = 17.69$, $p < .001$, $\eta^2 = .16$ as positive items (.54) were generally attributed better than negative (.46) and neutral (.42). *Least significant difference (LSD)* post-hoc tests confirmed that positive items were attributed better than negative ($p < .001$) and neutral items ($p < .001$). In addition, negative items were attributed better than neutral items ($p < .05$).

There was a significant two-way interaction between Valence and Age, $F(2,184) = 8.61$, $p < .001$, $\eta^2 = .09$. This interaction was due to the fact that source monitoring for positive items (.55) was better than source monitoring for negative (.40) and neutral items (.38) in the older group alone. *LSD* post-hoc tests revealed that positive items were attributed better than negative and neutral ones ($p < .001$), while source performance on negative and neutral items did not differ. Differently, in the younger adults, positive (.52) and negative items (.53) were attributed better than neutral items (.47). *LSD* post-hoc tests confirmed that there were no differences between positive and negative items, while positive and negative items were both significantly different from neutral ones ($p < .05$).

There was a significant two-way interaction between Age and Stimulation, $F(1,92) = 6.33$, $p < .05$, $\eta^2 = .06$. Stimulation increased the level of performance only in the older adults. In fact, older adults' source monitoring performance was .49 under stimulation and .40 under sham. *LSD* post-hoc tests confirmed that source performance increased under stimulation compared to sham ($p < .01$). Younger adults' performance was, instead, comparable across conditions (.50 under stimulation and .51 under sham).

The ANOVA also detected a two-way interaction between Valence and Stimulation, $F(2,184) = 8.37$, $p < .001$, $\eta^2 = .08$ because positive items (.59) were attributed better than negative (.45) and neutral items (.45) under stimulation (*LSD* post-hoc tests $p < .001$ for both comparisons), while positive (.47) and negative items (.48) were better attributed than neutral items (.40) under sham (*LSD* post-hoc tests $p < .01$ for both comparisons). No other interactions were significant.

Two relevant findings were worth further consideration. First, both younger and older adults were better able to correctly distinguishing the imagined than the seen source of items (a self-generation effect).

Second, stimulation particularly increased the ability to attribute positive words to the corresponding source. This pattern of data further supports our predictions. We thus conducted a series of planned comparisons to better clarify the role of stimulation in reality monitoring performance focusing on the imagined type of source condition only. As stated in the Introduction, of primary interest was the effect of stimulation on positive imagined items in the older adult group. The imagined positive condition under stimulation (.76) significantly differed compared with the imagined positive condition under sham (.52), $F(1,46) = 7.7$, $p < .01$, $\eta^2 = .14$. By contrast, younger adults did not show the same benefit, $F < 1$ (performance was .62 under stimulation and .56 under sham). This finding indicates that positivity effects for imagined items were augmented by stimulating the mPFC in the older adult group only. When we focused on imagined negative items in the younger adult group only and we compared source monitoring for imagined negative items under stimulation versus sham condition, we found that negative items were better attributed to the corresponding imagined source under sham (.68) than under stimulation (.58), $F(1,46) = 5.89$, $p < .05$, $\eta^2 = .11$. No differences were detected among older adults ($F < 1$). This pattern of results indicates that stimulation hindered the ability to correctly attribute negative words to the corresponding imagined source in the younger adults only and further points to the involvement of the mPFC in engaging more deeply with positive stimuli.

Recognition. We conducted an ANOVA with Valence (positive, negative, neutral) as within participants factor and Age (younger adults, older adults) and Stimulation (random noise *vs* sham) as a between-participants factor on HITs-FAs. Results are presented in Table 3. This analysis revealed a main effect of Age approaching the significant level, $F(1,92) = 3.48$, $p = .06$. In fact, recognition performance in younger adults tended to be higher (.41) than older adults' performance (.35). There was also a main effect of Valence, $F(2,184) = 21.09$,

Table 3 – Recognition scores (SE) in terms of HITs and FAs as a function of Stimulation, Valence, and Age.

Stimulation	Age	Valence	Recognition	
			HIT	FA
tRNS	Younger	Positive	.50 (.03)	.12 (.02)
		Negative	.71 (.03)	.20 (.03)
		Neutral	.49 (.03)	.14 (.03)
	Older	Positive	.56 (.04)	.22 (.05)
		Negative	.64 (.03)	.26 (.05)
		Neutral	.48 (.04)	.22 (.05)
SHAM	Younger	Positive	.55 (.04)	.15 (.03)
		Negative	.75 (.03)	.29 (.03)
		Neutral	.52 (.04)	.17 (.02)
	Older	Positive	.54 (.04)	.18 (.03)
		Negative	.71 (.03)	.28 (.04)
		Neutral	.53 (.03)	.18 (.04)

$p < .001$, $\eta^2 = .19$. We found that negative items (. 44) were recognized better than positive (.37) and neutral items (.33, *LSD* post-hoc tests, $p < .001$ for both comparisons). In addition, positive items were recognized better than neutral ones (*LSD* post-hoc test, $p < .05$). No other main effects or significant interactions were detected.

C biases. We conducted an ANOVA with Valence (positive, negative, neutral) as within participants factor and Age (younger adults, older adults) and Stimulation (random noise *vs* sham) as a between-participants factor on *C* biases. We only found a significant effect of Valence, $F(2,184) = 24.96$, $p < .001$, $\eta^2 = .21$. In fact, the *C* values were .75 for positive items, .18 for negative items and .76 for neutral items (*LSD* post-hoc tests, $p < .001$ for both comparisons). In general, participants show a conservative response bias, but were less conservative on negative items.

4. Discussion

In this study, we applied tRNS over mPFC to investigate whether random alternating currents in this region affect reality monitoring in aging. We will present the general findings first and subsequently focus on age-related differences. The main results can be summarized as follows. First, stimulation significantly improved participants' performance compared to sham stimulation. This finding is in line with numerous previous studies that show improvements in cognitive performance after stimulation (e.g., Coffman, Clark, & Parasuraman, 2014; Manenti, Cotelli, Robertson, & Miniussi, 2012; Penolazzi et al., 2010). Our study extends this finding to a reality monitoring task since tRNS applied during encoding improved participants' ability to remember whether an item had been imagined versus seen. Second, we found the classical self-generation effect since participants remembered items that were imagined better than items that were seen. This is consistent with previous studies (e.g., Johnson, Kounios, & Reeder, 1994) and confirms that participants are better at attributing source information when cognitive internal aspects are involved (e.g., thinking about the event, engaging in mental imagery, etc.) compared to externally perceived study conditions. Third, we found a positivity effect in reality monitoring. That is, there was a general source memory advantage for positive words compared to negative and neutral words. Our results generally mirrored main findings from the study by Kensinger et al. (2007, Experiment 2) but differed in that we found a general preference for positive information in the older adults.

In terms of age-related differences, we found an age by valence interaction in reality monitoring. In fact, we found a positivity effect in the older adults and a general emotional enhancement effect in the younger adults. This finding reflects the so-called age by valence interaction in memory (e.g., that is, older adults' greater focus on positive information as reported by Mather, 2016; Fairfield, Mammarella, & Di Domenico, 2013, 2015a; Fairfield, Mammarella, Di Domenico, & Palumbo, 2015b; Mammarella et al., 2013). In addition, we found an interesting interaction between age and stimulation. Indeed, our data showed that only older adults particularly benefited from stimulation. The two groups of younger adults, instead, had comparable levels of performance across conditions.

The absence of a clear-cut negativity bias in memory in younger adults and the finding that only stimulated older adults showed a source monitoring benefit, can be explained in terms of the role that mPFC may play in emotion processing. Our data, in fact, seem to indicate that when mPFC is activated, individuals engage more deeply with positive stimuli. Thus, tRNS may reduce the typical dispositional preference towards negative information, and in particular for imagined source information, compared to the sham group in younger adults. In addition, we found a selective improvement in source monitoring performance only in stimulated older adults. This may be due to the fact that tRNS during encoding caused an over-recruitment of mPFC, a key brain region involved in the processing of the types of source details (e.g., engaging in mental imagery and positively-charged information) that sustained reality monitoring especially in the older adults. The planned analysis on imagined source conditions were very informative in this regard as the positivity effect particularly increased after stimulation and especially for imagined items. Overall, thus, performance was much higher for positive information during imagery compared with other types of condition and stimuli in the older adult group. This finding is in line with other recent studies that found that mPFC is involved during imagery (e.g., Lin, Horner, Bisby, & Burgess, 2015) and especially when participants are required to engage in imagery for pleasant emotional situations (e.g., Costa, Lang, Sabatinelli, Versace, & Bradley, 2010).

This is also in line with previous studies suggesting that the benefit elicited from tRNS may be more pronounced under conditions that are more cognitively demanding (Gill, Shah, & Hamilton, 2014). Thus, a complementary assumption is that there was an over-recruitment of mPFC in aging due to the fact that older adults voluntarily addressed their cognitive resources to focus on positive items. The most cognitive demanding condition was, indeed, engaging in mental imagery for positive information. Consequently, older adults in the stimulation condition showed the greatest source memory advantage for this type of items.

Finally, our findings are also in line with a recent study by MacKenzie, Powell, and Donaldson (2015) showing that positive emotions can help reduce source-monitoring errors. Previous research has demonstrated, in fact, that older adults perform significantly worse than younger adults on reality monitoring tasks, and patients with Alzheimer's Dementia perform very poorly compared with healthy controls in source monitoring tasks (e.g., El Haj & Kessels, 2013; El Haj, Fasotti, & Allain, 2012; Fairfield & Mammarella, 2009; Goldman, Winograd, Goldstein, O'Jile, & Green, 1994; Multhaup & Balota, 1997). However, emotional source details are better attributed than other types of source information (e.g., Kensinger et al., 2007; Mammarella, Fairfield, & Di Domenico, 2012). Based on our results and previous findings about the impact of transcranial stimulation on memory, treatment of source monitoring failures via stimulation over the mPFC seems thus a promising avenue.

Support for this claim can also be found in studies with schizophrenia patients. These studies support the hypothesis that hallucinations in schizophrenia result from particular

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deficits in reality monitoring (see Ditman & Kuperberg, 2005, for a review). In addition, it is also well-known that schizophrenia is associated with dysfunction in medial PFC, an area we previously discussed as being especially sensitive to monitoring self- versus other generated information (e.g., Vinogradov, Luks, Schulman, & Simpson, 2008). These data, coupled with recent findings (Mondino, Haesebaert, Poulet, Suaud-Chagny, & Brunelin, 2015) that have shown a reduction of hallucinations in a group of schizophrenia patients when stimulating frontal areas, indicate that stimulating mPFC may, in general, sustain internal versus external source discriminations.

With regards to recognition scores and memory biases, we found no significant effects of stimulation on recognition memory performance. Participants in the stimulation and sham groups did not differ significantly in terms of discrimination and biases (see Matzen, Trumbo, Leach, & Leshikar, 2015 for similar results). One explanation lies in the different memory processes tapped by these two memory tasks. In a recognition task, in fact, participants can use familiarity-based judgments to indicate whether an item was encountered before or it was new. Differently, source monitoring involves more detailed memory for the event and is typically more recollection-based. This difference can make recognition easier and may mask improvements in encoding due to tRNS effects. This finding is also in line with previous studies suggesting that behavioral effects elicited from stimulation can be greater under conditions that are more cognitively demanding (Gill et al., 2014). In line with this hypothesis another intriguing aspect is that, differently from source memory, recognition was better for negative items and participants were less conservative on them. We assume that participants did not base their old-new judgments on qualitative features (e.g., number of cognitive operations engaged during encoding) rather they based their response on familiarity alone. This was true independently of stimulation. It may be that the way in which participants use familiarity versus recollection-based processes leads to a specific memory for information with emotional relevance.

In terms of methodology, one can argue that in addition to the mPFC, the occipital lobe was also stimulated and could contribute to the generation of the visual forms of the auditory words in the imagery encoding condition. First, we introduced a positive DC offset (+.5 mA) to the stimulation in order to produce a polarity-specific randomly oscillating current on the mPFC that is similar to tDCS effects. Second, the low contribution of occipital area can be inferred by the fact that participants under stimulation did not respond "seen" to "imagined" items more often (.22) compared with "imagined" to "seen" items (.40), but actually they showed the opposite pattern. The rationale being that a series of studies (e.g., Gonsalves et al., 2004; Kensinger & Schacter, 2005) found that activity in regions implicated in mental imagery (e.g., visual cortex) increased the probability of later making reality-monitoring errors. Presumably, participants retrieve the visual information generated during mental imagery, but believed that it had come from visual presentation of the item. We did not observe a similar pattern of results in our study.

To conclude, our study has several limitations. A series of studies (e.g., Chaieb, Paulus, & Antal, 2011; Terney et al., 2008) found that tRNS over the primary motor cortex (M1) can induce elevations in cortical excitability outlasting the duration of stimulation. The fact that the source monitoring task immediately followed the encoding phase makes it difficult disentangling the role of stimulation from encoding versus retrieval processes. However, stimulation aimed at transiently modulating cortical excitability is, in general, short-lived and, most important, seems to be dependent upon stimulus duration and intensity. In addition, the cellular targets of transcranially applied electrical currents include morphologically and functionally distinct networks of cell neurons compared to the M1 (Radman, Ramos, Brumberg, & Bikson, 2009) and may show different degree of after-effects. Further experiments should also control for after-effects of tRNS-induced plasticity over the mPFC.

Another limitation is that we did not include a control site to examine whether effects on source memory performance following stimulations were specific to PFC stimulation. However, given that only the source memory (internal *vs* external attribution) but not the overall recognition performance or the recognition biases were modulated by the stimulation, we can assume that stimulating PFC rather than any part of the brain region is crucial in correct attribution of items to internal source as it happens in reality monitoring. It would of importance to seek converging evidence from studies that employ stimulation over control sites to strengthen the current findings and examine the specific role of the PFC in the network that support encoding processes in reality monitoring.

As far as we know, this is one of the first studies to present data regarding stimulation of older adults during an emotional reality-monitoring task. Although our results seem promising, they need to be taken with caution since the effects of transcranial stimulation on complex cognitive functions such as reality monitoring may be variable (see Horvath, Forte, & Carter, 2015 for a review). That is, it may be that reality-monitoring processes are differentially affected by tRNS according to the function involved (e.g., refreshing, noting, etc.). In addition, we observed a large variability in reality monitoring performance across our participants. One explanation may be related to the sophisticated behavioral paradigm that was adopted. In fact, participants were engaged in a letter-height decision task while studying seen versus imagined valenced words and, subsequently, took a surprise reality-monitoring task. Again, the presence of different types of source information (imagined *vs* seen and the emotional connotation) may differentially affect performance among participants. More studies with different experimental designs (e.g., within-subjects, intentional learning procedure) are therefore needed to better disentangle the contribution of different types of stimulation and help understand the reality monitoring-emotion interaction in aging brain.

5. Conclusions

Overall, the results of this study suggest that reality-monitoring performance is enhanced by tRNS during encoding, and that this improvement is particularly evident for

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older adults when attributing positive memories to an internal source. These results add to the growing body of literature that indicates that tRNS can enhance different memory functions and may lead to a reduction of source misattributions in aging. They also suggest some intriguing avenues for future research, including the impact of tRNS on source retrieval rather than encoding and the role of stimulation during processing of different source details in aging.

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Conflict of interest

There are no conflicts of interest.

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