



Differential Modulation of Performance in Insight and Divergent Thinking Tasks with tDCS

Vinod Goel,^{1,2,3} Iveta Eimontaite,² Amit Goel,⁴ and Igor Schindler²

¹York University, ²University of Hull, ³IRCCS Fondazione Ospedale San Camillo, ⁴McGill University

Correspondence:

Correspondence concerning this article should be addressed to Vinod Goel, Department of Psychology, York University, Toronto, Ontario, M3J 1P3 Canada, or via email to vgoel@yorku.ca.

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While both insight and divergent thinking tasks are used to study creativity, there are reasons to believe that the two may call upon very different mechanisms. To explore this hypothesis, we administered a verbal insight task (riddles) and a divergent thinking task (verbal fluency) to 16 native English speakers and 16 non-native English speakers after they underwent Transcranial Direct Current Stimulation (tDCS) of the left middle temporal gyrus and right temporo-parietal junction. We found that, in the case of the insight task the depolarization of right temporo-parietal junction and hyperpolarization of left middle temporal gyrus resulted in increased performance, relative to both the control condition and the reverse stimulation condition in both groups (non-native > native speakers). However, in the case of the divergent thinking task, the same pattern of stimulation resulted in a decrease in performance, compared to the reverse stimulation condition, in the non-native speakers. We explain this dissociation in terms of differing task demands of divergent thinking and insight tasks and speculate that the greater sensitivity of non-native speakers to tDCS stimulation may be a function of less entrenched neural networks for non-native languages.

INTRODUCTION

Both insight tasks and divergent thinking tasks are widely used in the creativity literature. There is, however, very little discussion about the similarities and differences between them and the implications for our understanding of creativity (DeYoung, Flanders, & Peterson, 2008; Gabora, 2010; Gilhooly & Fioratou, 2009; Gilhooly & Murphy, 2005; Goel, 2014). While both are bona fide creativity tasks, they do differ along a number of features. Insight problems are widely characterized by an impasse (no obvious solution), fixation (repetition of the same types of unsuccessful steps), incubation (disengagement of the problem), and a sudden solution (the “aha” experience) (Duncker, 1945). They are a subset of well-structured problems (Goel, 1995, 2010, 2014), but differ from the larger set, in that the goal state lies in a part of the problem space that is unconnected (or remotely connected) to, or not “visible” from the current state of the problem solver. The phenomenological experience of the problem solver is one of being suddenly transferred from the current node in the state space to a node that is near the goal state. Once this mental set shift or reconceptualization occurs, the problem solver can access the goal state using standard problem-solving processes (Ohlsson, 1992; Öllinger & Knoblich, 2009).

Divergent thinking or “semantic spread” problems, on the other hand, involve the gradual development of solutions using mechanisms such as “defocused attention” (Vartanian, 2009).¹ These tasks differ from insight problems in that they

are typically a subset of ill-structured problems (rather than well-structured problems); involve locally based divergent transformations as opposed to discreet mental set shifts to distant parts of the state space; and there is no “aha” experience associated with the solution state. These differences between insight problems and divergent thinking problems are not meant to suggest that all creativity problems must fall into one or the other category. Real-world creativity problems will share features of both categories (Goel, 2014).² Our contention is that these differences in task demands are bound to result in the deployment of different cognitive and neural mechanisms.

To test the hypothesis that insight and fluency tasks implicate different neural systems, we administered a linguistic insight task and a linguistic divergent thinking task to normal healthy participants after they underwent tDCS brain stimulation. tDCS is an old, recently rediscovered technology that affects brain function by applying a weak electrical current to the scalp. The positive/anodal stimulation depolarizes the region under the electrode while cathodal/negative stimulation hyperpolarizes the region (Been, Ngo, Miller, & Fitzgerald, 2007). Recent studies have shown that following direct current stimulation, polarization specific to the proximity of the anode or cathode occurs in the soma and synaptic terminals of both pyramidal and non-pyramidal tract neurons (Rahman et al., 2013; Stagg & Nitsche, 2011). Studies using tDCS on the human motor cortex report increased cortical excitability under the

anode and the opposite effect under the cathode (Nitsche et al., 2008; Nitsche & Paulus, 2000; Stagg et al., 2009). A similar pattern is observed for studies using tDCS in cognitive tasks where, in most cases, anodal stimulation of a targeted cortical area results in increased functionality compared to weaker or absent effects for cathodal stimulation of that same area (Jacobson, Koslowsky, & Lavidor, 2012).

At least two tDCS studies have targeted creativity to date. Cerruti and Schlaug (2009) showed that anodal stimulation of the left dorsolateral prefrontal cortex (and cathodal stimulation of the right supraorbital region) improves performance in the Remote Associates Task (RAT). Chi and Snyder (2011) reported that anodal stimulation of the right anterior temporal lobe, along with cathodal stimulation of the left anterior temporal lobe, increases performance in the Matchstick Arithmetic Task. The specific positive effects of anodal stimulation in frontal and temporal areas can be explained by different task demands and modality (linguistic versus pictorial) of the Remote Associates Task and the Matchstick Arithmetic Task (Bowden, Jung-Beeman, Fleck, & Kounios, 2005). Furthermore, stimulation of the left dorsolateral prefrontal cortex seems to affect a wide range of cognitive tasks (Boggio, Zaghi, & Fregni, 2009; Fregni et al., 2005; Priori et al., 2007).

Our focus is not on the involvement of any specific brain areas, but rather on possible dissociations (Caramazza, 1984; Shallice, 1988) across insight and divergent thinking tasks. Insight was measured with a riddles task, and divergent thinking with a verbal fluency task. Both of these tasks have been previously used in the creativity literature (Carlsson, Wendt, & Risberg, 2000; Luo & Niki, 2003). The anatomical areas for tDCS were determined based on fMRI studies showing left middle temporal gyrus (IMTG/BA 21) involvement in verbal fluency tasks (Baldo, Schwartz, Wilkins, & Dronkers, 2006; Gourovitch et al., 2000; Henry & Crawford, 2004; Loring, Meador, & Lee, 1994; Martin, Loring, Meador, & Lee, 1990) and right temporo-parietal junction region (rTPJ/BA 40, 22) involvement in the Remote Associates Task (Bowden & Jung-Beeman, 2003; Jung-Beeman et al., 2004).

We expected the stimulation to differentially affect the riddles/insight task and the verbal fluency task. More specifically, we expected depolarization of the right temporo-parietal junction region and hyperpolarization of left middle temporal gyrus to result in improved performance on the riddles/insight task while the depolarization of left middle temporal gyrus and hyperpolarization of right temporo-parietal junction was expected to result in improved performance on the verbal fluency task. Also, both tasks were language-based, and given that differences in proficiency and exposure to a language may impact its neural organization (Perani & Abutalebi, 2005), for example, in terms of different levels of neural entrenchment, and corresponding differences in relative

sensitivity to the modulatory effects of brain stimulation, we recruited both native and non-native English speakers and anticipated that non-native speakers may be more affected by tDCS stimulation than native speakers.

METHODS

PARTICIPANTS

Thirty-two students took part in the study (mean age = 26.56 years, SD = 9.09). Since the tasks were linguistic and our subject pool contained both native and non-native English speakers, we controlled for native language. Sixteen participants were native English speakers (7 females, mean age = 23.42 years, SD = 8.24), and 16 were non-native English speakers (8 females, mean age = 25.63 years, SD = 4.01), but sufficiently fluent to attend an English university (IELTS Score of 5.5 and above). The mean age of language acquisition for the non-native speakers was 16.06 years, SD = 6.77 ranging from 7 to 27 years. All participants were right-handed and were screened for tDCS exclusion criteria such as the use of psychotropic medication, and had normal or corrected to normal vision. Written informed consent was obtained from all the participants before they took part in the study. The study was approved by the departmental ethics committee.

STIMULI AND TASKS

Two tasks were used to assess potential tDCS effects on creativity: a Riddle/Insight Task and a Phonemic Verbal Fluency Task. Both tasks comprised four sets of items, such that one set could be used with each tDCS condition and administered to all participants. The order of the tasks was counterbalanced across the 32 participants. All answers were recorded with an audio recorder and later transcribed for subsequent analysis.

Riddle/Insight Task

Riddles were presented in five sets (four experimental sets and one alternative riddle set) consisting of five riddles in each experimental set. Each riddle consisted of a short paragraph (1–3 sentences) such as “why are 1992 pound coins worth more than 1991 pound coins?”. The complete list of riddles appears in Appendix A. At every session participants were sequentially presented with five riddles printed in black on a 6 × 21 cm white piece of paper (font: Times New Roman, size: 12). The order of the riddles was counterbalanced. The participants were instructed to read the riddle and indicate whether they had seen it previously. Any riddles familiar to participants were replaced by substitutes from an alternative set. Participants were given 90 seconds, following a verbal start signal, to solve each riddle. They were asked to solve the riddles as accurately and quickly as possible. The time for each trial was recorded

in seconds with a stopwatch. Answers were considered to be correct as long as they fit the riddle's description (e.g., for the riddle: What has a neck and no head, two arms but no hands? "A shirt" is the correct answer but "sweater" and "jacket" were considered equally correct).

Phonemic Verbal Fluency Task

The Phonemic Verbal Fluency Task (Benton, 1968; Spreen & Benton, 1969) was administered in four sets consisting of three different target letters per set. In each experimental session, participants completed three 60-second trials. For example, in the first trial participants were asked to generate as many words as possible beginning with the letter "F" in the second beginning with "A," and in the third with "S." Letters in each of the four sessions differed. The presentation order was counterbalanced. The use of proper nouns, that is, names of people or places (e.g., Hull, Mary, McDonald's) was not allowed. Timing was controlled by a stopwatch with recording onset following a verbal "go" signal. The number of words generated was tallied up at the end of the session and a mean for all three trials was calculated.

TRANSCRANIAL DIRECT CURRENT STIMULATION (tDCS)

Bipolar stimulation was delivered by an Eldith DC stimulator (neuroConn®) connected to a pair of rubber electrodes (surface area $4 \times 4 \text{ cm}^2$), which were inserted in saline-soaked sponge pockets. During verum stimulation, a constant current was applied with an intensity of 2 mA for 20 minutes, including a fade-in and fade-out phase of 5 seconds each. For sham stimulation, the system was set at placebo mode inducing ramp periods at the start and end of the 20-minute interval to provide the somatosensory experience of verum stimulation, thereby ensuring that the participants were blind to the type of stimulation.

To maximize comfort, the experimenter monitored impedance throughout the tDCS sessions based on the device's automatic readings with thresholds set at an upper limit of $< 8 \text{ k}\Omega$ and a voltage of $< 26 \text{ V}$. Stimulation was always delivered before the experimental tasks, which were carried out immediately after.

The anatomical areas of interest for tDCS were determined as noted in the introduction. Both areas were anatomically localized based on the following MNI coordinates: $x = 66$, $y = -34$, $z = 24$ for rTPJ and $x = -62$, $y = -42$, $z = -4$ for lMTG. However, it should be kept in mind that the electrode surface area was $4 \text{ cm} \times 4 \text{ cm}$ and there is diffusion of the electrical current through the scalp and cranium, thus the areas affected by the stimulation are much larger. These coordinates were converted into EEG electrode positions according to the 10–20 electrode system using the Münster T2T converter (<http://www.neuro03.uni-muenster.de/ger/t2tconv/conv3d.html>). rTPJ was identified as CP6 and lMTG as half the distance

between TP7 and CP5. In addition, the contralateral homologues were localized with left IPL as CP5 and rMTG as half the distance between TP8 and CP6 (Figure 1). Accordingly, for cathodal lMTG stimulation, the center of the Cathode was placed over the lMTG and the center of the Anode over rTPJ. For anodal lMTG stimulation, the positions of the Anode and Cathode were reversed. There were four stimulation conditions: no stimulation, sham stimulation, anodal lMTG and cathodal rTPJ, cathodal lMTG and anodal rTPJ. The electrode setup for sham stimulation was randomly allocated with half the participants receiving one of the two verum stimulation configurations, respectively.

RESULTS

In the Riddle/Insight Task, the dependent measures were the proportion of correct responses (accuracy rate) and mean response time. In the Phonemic Verbal Fluency Task, the dependent measure was the average number of words generated across the three letters in each stimulation session.

Initially, the sham and no stimulation conditions were compared using pairwise t-tests (two-tailed, $\alpha = 0.05$). There was neither a significant difference between the mean number of correct answers in the Riddle/Insight Task (mean = 0.46, $SD = 0.29$ vs. mean = 0.45, $SD = 0.24$; $t(31) = .189$, $p = .852$) nor between the mean number of words generated in the Phonemic Verbal Fluency Task (mean = 13.21, $SD = 4.32$ vs. mean = 13.80, $SD = 3.79$; $t(31) = -1.19$, $p = .242$). Consequently, the data for both conditions were collapsed into a single "control" condition.

Following this, separate 3×2 mixed-design ANOVAs were carried out for each task with the within-subject factor Stimulation (control, anodal lMTG/cathodal rTPJ, cathodal lMTG/anodal rTPJ) and the between-subject factor Language (native English speakers, non-native English speakers). Simple main effects were analyzed using independent t-tests (two-tailed, $\alpha = 0.05$).

RIDDLE/INSIGHT TASK

A mixed-design 3×2 ANOVA showed that the main effects of Stimulation and Language were significant, after a Greenhouse-Geisser correction ($F(1.54, 46.07) = 7.98$, $p = .002$ and $F(1,30) = 5.97$, $p = .021$, respectively). The Stimulation \times Language interaction was not significant.

Post-hoc, within-subject comparisons with paired t-tests revealed that a higher number of riddles were solved in the cathodal lMTG/anodal rTPJ condition than the control condition ($t(31) = 2.95$, $p = .006$), and the anodal lMTG/cathodal rTPJ condition ($t(31) = 3.18$, $p = .003$). There was no significant difference in the number of solved riddles between the control condition and anodal lMTG/cathodal rTPJ condition ($t(31) = 1.67$, $p = .106$; see Figure 2).

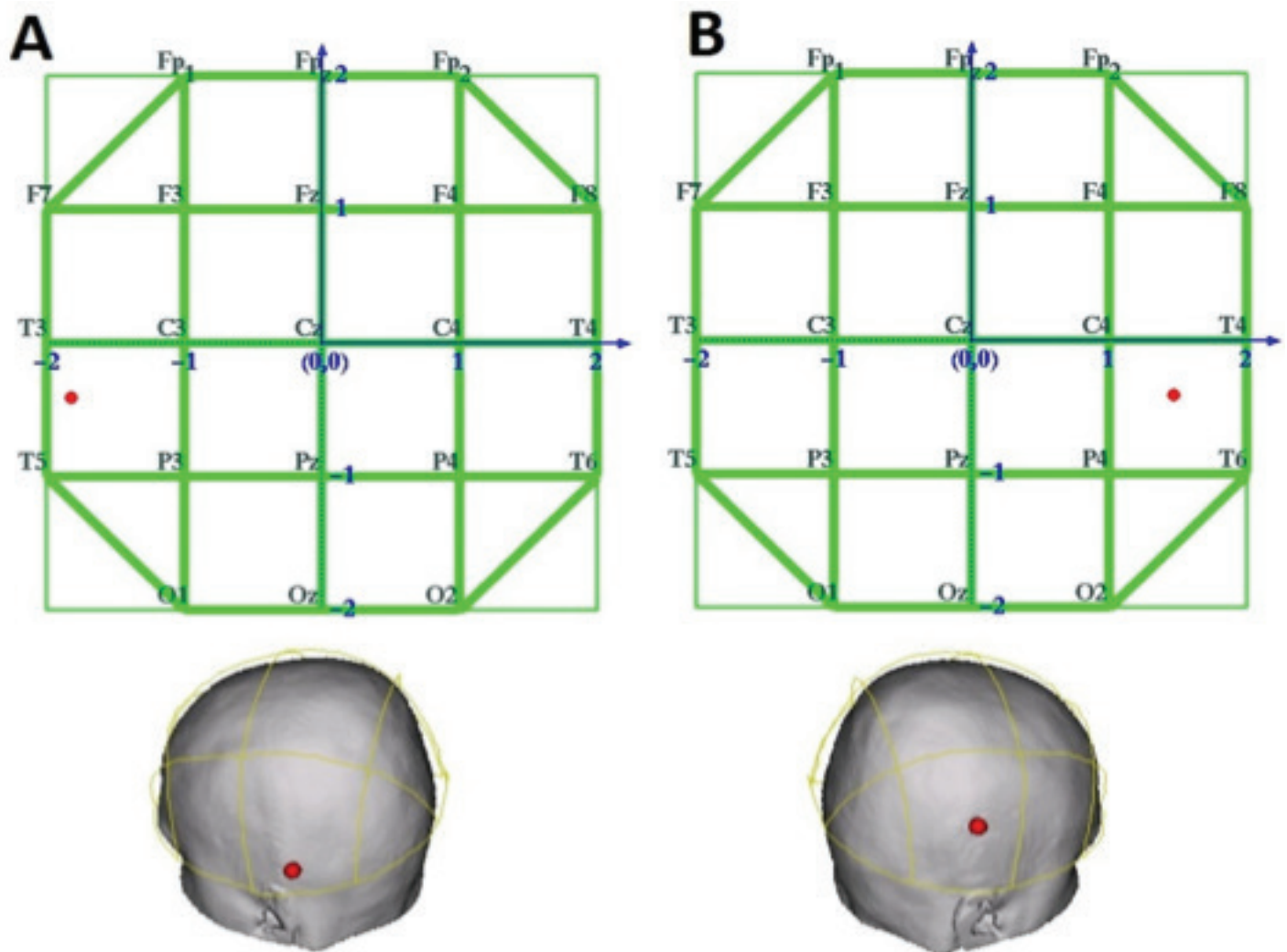


Figure 1. Basic target points on an EEG mesh and on a 3D head with vertex and inion lines generated by Münster T2T converter. (A) lMTG; (B) rTPJ.

The main effect of Language was also significant, showing that native and non-native English speakers performed significantly differently. The mean accuracy score across all three stimulation conditions for native speakers was 0.56 ($SD = .12$), versus 0.40 ($SD = .23$) for non-native speakers (Figure 3).

Despite the lack of a Language \times Stimulation interaction, we chose to explore the simple main effects of Language due to the linguistic nature of the task and the significant main effect of Language noted above. We performed two separate one-way repeated measures ANOVAs with the within factor Stimulation for native and non-native English speakers. Native English speakers showed no significant effect of Stimulation on the accuracy rate ($F(2, 30) = 1.71, p = .198$). In contrast, there was a significant main effect of Stimulation for non-native speakers ($F(1.45, 21.76) = 9.83, p = .002$, Greenhouse-Geisser corrected).

Post-hoc comparisons of non-native English speakers revealed that performance on all experimental conditions differed from each other. The accuracy rates following anodal lMTG/cathodal rTPJ stimulation were lower than in the control condition, with the difference approaching significance ($t(15) = 2.28, p = .037$, Bonferroni corrected for multiple comparison alpha-value = .017). Accuracy rates following cathodal lMTG/anodal rTPJ stimulation were significantly higher than for the control condition ($t(15) = -2.95, p = .010$). The difference in accuracy rates between anodal lMTG/cathodal rTPJ stimulation and cathodal lMTG/anodal rTPJ stimulation was also significant, ($t(15) = 3.48, p = .003$; Figure 4).

Finally, a 3×2 mixed-design ANOVA on response times for correctly solved riddles with the within-subject factors Stimulation and the between-subject factor of Native Language yielded neither significant main effects of Stimulation or Native Language, nor a significant interaction between Stimulation and Native Language.

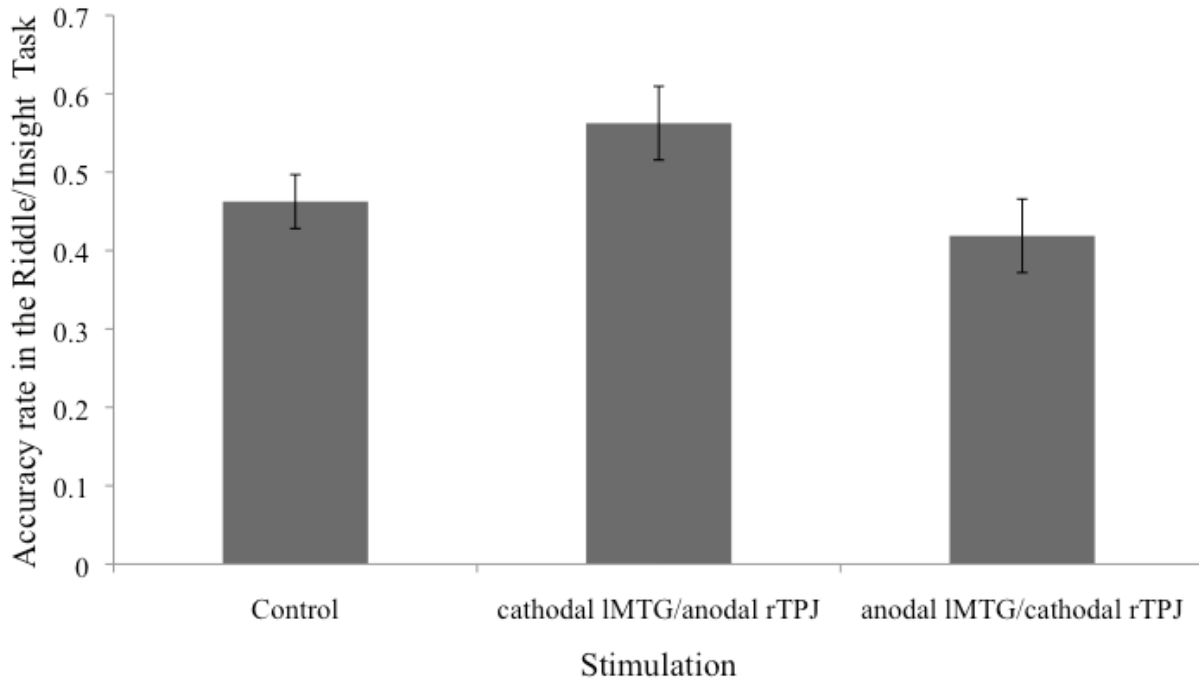


Figure 2. Mean accuracy rates (\pm 1 SEM) in the Riddle/Insight Task as a function of different tDCS stimulation conditions.

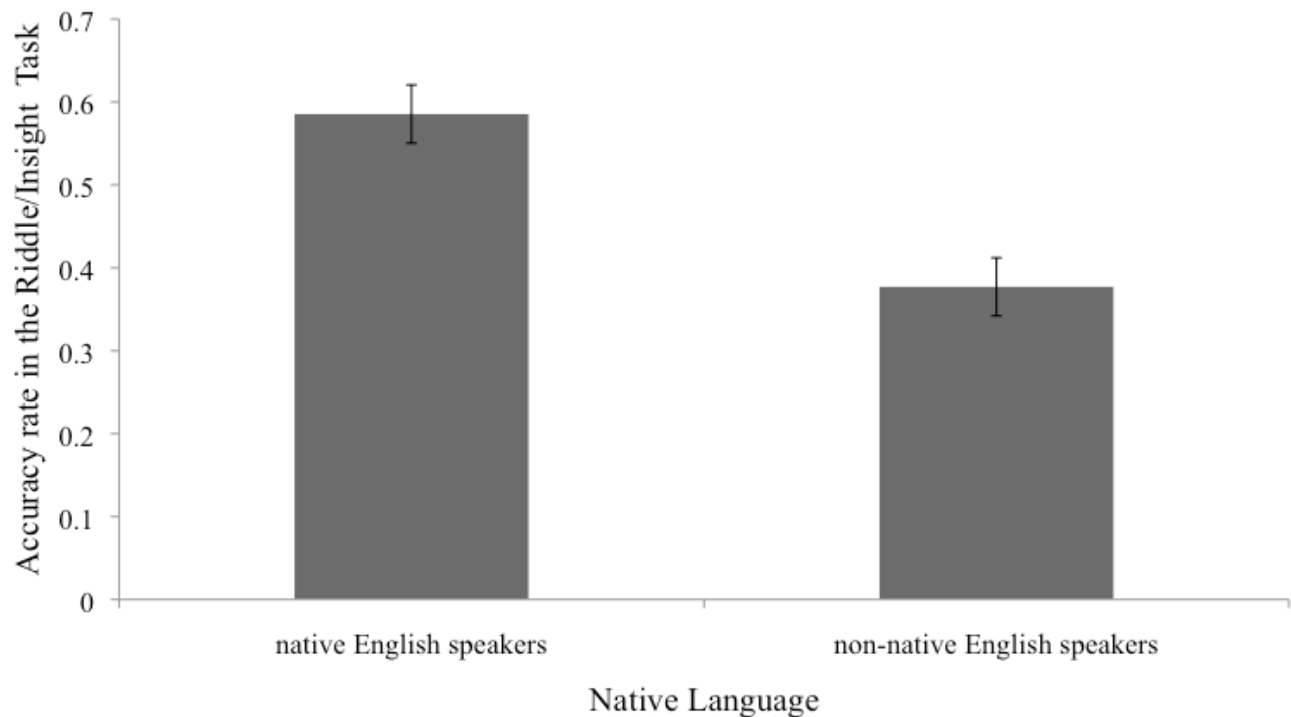


Figure 3. Mean accuracy rates (\pm 1 SEM) for native and non-native English speakers in the Riddle/Insight Task.

Discussion: Riddle/Insight Task

Our results indicate that although response times were similar, native English speakers solved more riddles than non-native speakers, and stimulation improved performance on the task. In particular, depolarization of the right TPJ and hyperpolarization of left MTG resulted in increased performance relative to both, the control condition, and the reverse stimulation condition. While there was no significant Language \times Stimulation interaction, the performance on the task may still be dependent on native language, in that the main effect of stimulation was largely driven by improved performance of the non-native speakers during the depolarization of the right TPJ and hyperpolarization of left MTG condition. The native English speakers were largely unaffected.

How do we account for these results? Our normal understanding of words and sentences relies upon connotative meanings derived from background knowledge and contextual information. For example, given the question “what has a neck and arms but no head or hands?” we are initially stumped because neck and arms belong to living things and are accompanied by heads and hands. If we search the class of living things, there are no exceptions that readily come to mind. However, by association, the terms “neck” and “arms” are also literally applied to parts of clothing that cover necks

and arms. Solving the riddle requires us to suppress the normal interpretation of the terms and search for alternate meanings, usually in a very different semantic space. In the above example, if we suppress the search for living things without heads and arms and make the association between the terms “neck” and “arm” to parts of clothing that cover these body parts, the riddle immediately resolves itself.

The main effect of stimulation can be explained by the fact that hyperpolarization of the left middle temporal gyrus (BA 22), an area commonly involved in routine semantic processing (Troyer, Moscovitch, Winocur, Alexander, & Stuss, 1998), may hinder jumping to the “normal” interpretation, while depolarization of the right superior temporal gyrus and parietal lobule, areas involved in unusual or metaphorical word meanings/semantic processing (Jung-Beeman, 2005; Mashal, Faust, & Hendler, 2005; Seger, Desmond, Glover, & Gabrieli, 2000) may facilitate the search for alternative interpretations.

The fact that native speakers performed better than non-native speakers in the task is not surprising. Native speakers have a much more proficient, flexible, versatile command of the English language and word meanings. They should be better at finding relevant alternate meanings/interpretations of the terms (though not necessarily better at suppressing the “normal” meanings).

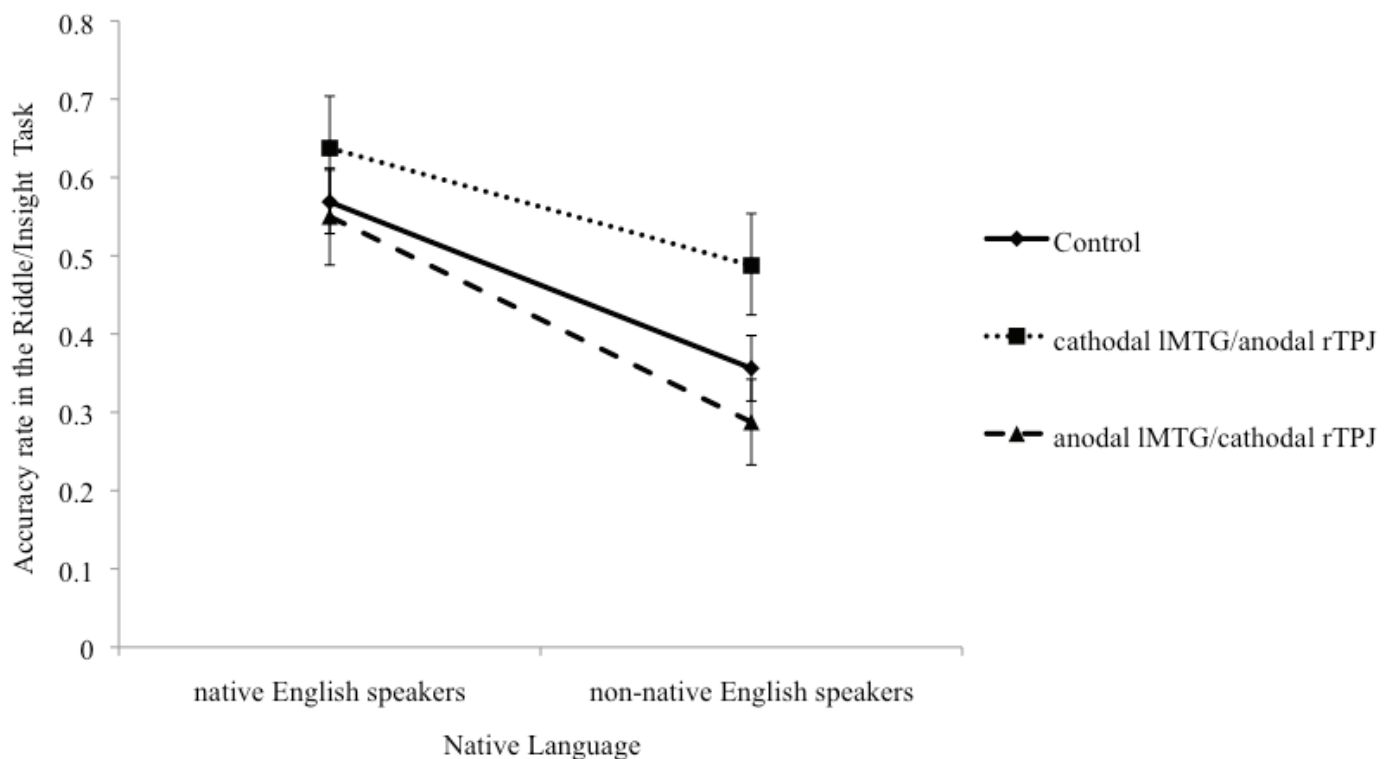


Figure 4. Mean accuracy rates (\pm 1 SEM) for native English speakers and non-native English speakers following different tDCS Stimulation conditions in the Riddle/Insight Task.

The fact that the main effect of tDCS stimulation was driven by non-native speakers is intriguing. There are several possible explanations for this finding. The first possibility is that fluent (but late acquisition) non-native speakers (like most of our participants) require access to additional higher order cognitive processes to display the same level of semantic flexibility as native speakers, and our chosen stimulation sites affected these cognitive processes. While this explanation is consistent with the fact that native speakers performed better than non-native speakers, it cannot account for the fact that the former displayed the same pattern of results, in response to stimulation, as the latter (albeit at a non-significant level).

A second possibility is that different neural substrates may subserve first- and second-language acquisition and processing. While the issue is unsettled, there is some agreement that the age of second-language acquisition, and the degree of proficiency in and exposure to the second language, affects its neural organization (Perani & Abutalebi, 2005). Some data suggest that a second language acquired during the “critical period” (i.e., prior to puberty) (Snow & Hoefnagel-Hohle, 1978) utilizes the same neural structures as the native language, while a second language acquired later in life (beyond the “critical period” of language acquisition) relies on slightly different but overlapping neural structures as the first language (Perani et al., 2003; Wartenburger et al., 2003). Of our 16 non-native speakers, 10 learned English after the age of 10. Thus, another possible explanation of why the stimulation results were largely driven by non-native speakers is that the location of English-language processing networks may be slightly different in the non-native speakers than the native speakers, and our stimulus location was such that it had a greater impact on the former than the latter. However, this explanation requires a chance component as we did not actually map out the linguistic neural representations of our participants.

The third and most plausible explanation is that the neural networks for English language comprehension and generation are not as well entrenched in non-native speakers as in native English speakers. As such, tDCS had a much greater effect on non-native speakers.

PHONEMIC VERBAL FLUENCY TASK

A 3×2 mixed-design (Stimulation \times Language) ANOVA indicated no significant main effects of Stimulation or Language. There was, however, a significant Stimulation \times Language interaction ($F(2, 60) = 3.94, p = .025$).

To investigate the interaction further, we performed independent t-tests comparing native and non-native English speakers' performance in all three stimulation conditions. There was no significant difference between native English speakers and non-native English speakers in either stimulation condition.

As with the Riddle/Insight Task, we performed a one-way repeated measures ANOVA for native and non-native English speakers separately. There were no significant differences in the number of words generated by native English speakers across the three stimulation conditions (see Figure 5). The ANOVA for non-native speakers, however, did show significant differences across stimulation conditions ($F(2, 30) = 4.27, p = .023$). A post-hoc paired t-test showed a trend difference between the cathodal IMTG/anodal rTPJ stimulation and anodal IMTG/cathodal rTPJ stimulation conditions ($t(15) = -2.51, p = .024$, Bonferroni corrected for multiple comparison alpha-value = .017). Differences between the control vs. the two verum stimulation conditions were not significant ($t(15) \leq 1.59, p \geq .121$).

Discussion: Phonemic Verbal Fluency Task

These results indicate that overall, tDCS stimulation did not affect participants' performance on the verbal fluency task, and that native and non-native English speakers were equally good at the task. However, the non-native speakers were selectively affected by the tDCS stimulation and performed more poorly in the cathodal IMTG/anodal rTPJ stimulation condition versus the anodal IMTG/cathodal rTPJ stimulation condition.

Verbal fluency tasks are different from riddle tasks in that they do not require search inhibition or movement to a different semantic space. The task would benefit from strategies that facilitate search within the given space. The Phonemic Verbal Fluency Task requires searching the lexicon, but along a nonstandard, phonological criterion. A large vocabulary and language proficiency are necessary criteria for the task. The literature on verbal fluency tasks is actually divided into semantic fluency tasks (such as generating members of the category “bird”) and phonemic fluency tasks, such as used here. It is largely accepted that, while frontal lobe lesions impair both phonemic and category fluency tasks (Baldo & Shimamura, 1998), semantic fluency tasks are more affected by temporal lobe lesions (Gourovitch et al., 2000; Monsch et al., 1997), whereas phonemic fluency tasks are more affected by left frontal lobe lesions (Milner, 1964; Perret, 1974; Stuss et al., 1998). However, neuroimaging studies and a meta-analysis of the lesion studies suggest that the distinctions are much more subtle than originally thought, and that temporal lobes (L > R) are also involved in phonemic fluency tasks (Baldo et al., 2006; Gourovitch et al., 2000; Henry & Crawford, 2004; Loring et al., 1994; Martin et al., 1990). Given this, we would expect that hyperpolarization of the left middle temporal gyrus would interfere with letter to word generation while depolarization should perhaps improve performance. Half of this expectation was satisfied in the case of non-native speakers. We found that the hyperpolarization of IMTG (and depolarization of rTPJ) compared to depolarization of the

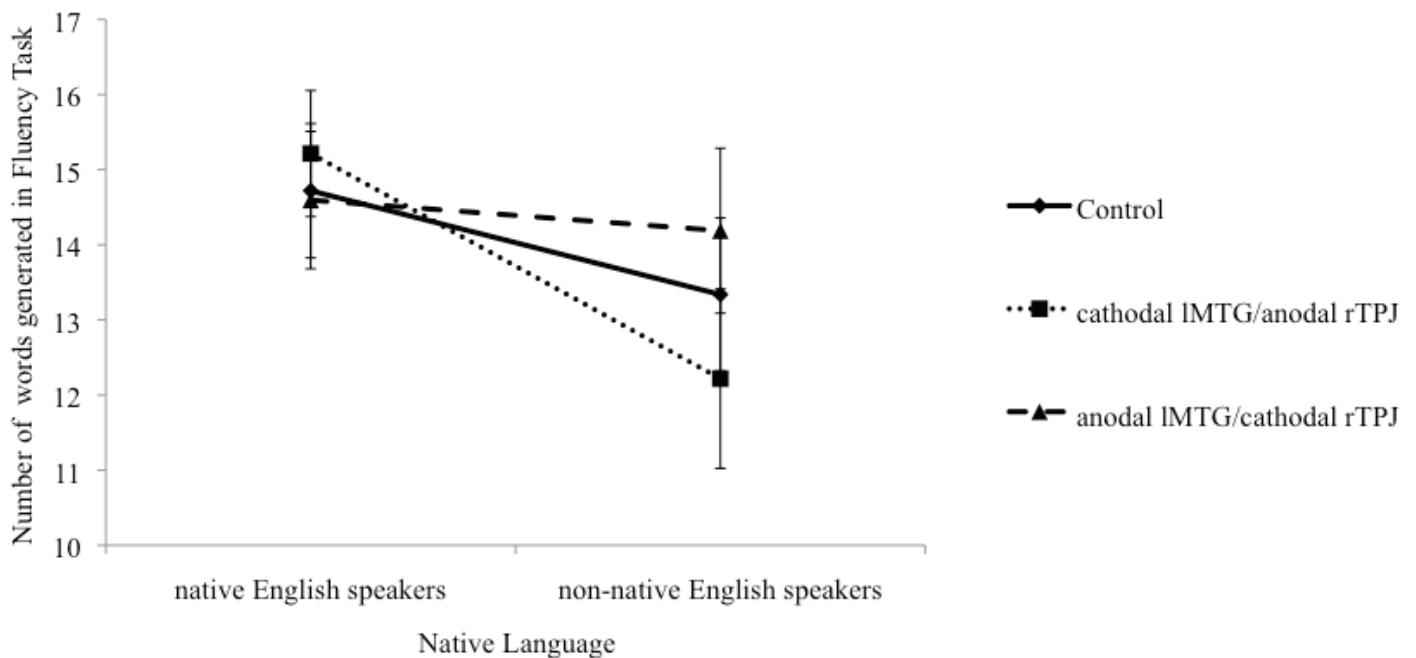


Figure 5. The Mean number of words (\pm 1SEM) produced in the Phonemic Verbal Fluency Task by native and non-native English speakers in the three stimulation conditions.

lMTG (and hyperpolarization of rTPJ) resulted in a decrease in verbal fluency performance in non-native speakers, but the depolarization of left MTG did not improve performance in either group.

In the fluency task, there was a significant Language \times Stimulation interaction, with non-native English speakers being more affected by the stimulation. The same three factors considered above, in the Riddles Task, need to be considered here. First, as there was no difference in performance between native and non-native speakers, we may be able to discount the possibility that non-native speakers found the task more difficult and had to recruit additional cognitive resources, and that the stimulation sites affected this recruitment. Second, it is possible that neural networks for English-language processing are in slightly different locations in the non-native speakers and happen to be more aligned with our stimulation locations than those of native speakers, but again, this explanation involves an element of chance. Third, as in the case of the Riddles Task, the most plausible explanation seems to be that the English language processing networks in non-native speakers are not as well entrenched as those of the native English speakers and are therefore more susceptible to tDCS.

GENERAL DISCUSSION AND CONCLUSION

The reported results suggest that depolarization of right TPJ and hyperpolarization of left MTG facilitate performance on the Riddles Task. Interestingly, not only does the same

stimulation pattern not increase performance in the Phonemic Verbal Fluency Task, it actually decreases performance, at least for non-native speakers. Our primary focus here is not on the specific neural regions stimulated, but that the same pattern of stimulation has very different effects on the two tasks. The differential effect of tDCS stimulation on verbal riddles and verbal fluency tasks highlight a dissociation and the possible involvement of different neural systems, consistent with the claim that insight and divergent thinking tasks place differential demands on the cognitive system (Goel, 2014). There will undoubtedly be other lines of dissociation across creativity tasks. For example, Vartanian (2012) recently completed a meta-analysis showing dissociation of systems involved in analogical and metaphor creativity tasks.

The fact that the impact of the stimulation was greater in non-native speakers than native English speakers, in both tasks, is intriguing. One possibility is that the effect of the stimulation is restricted to non-native speakers. However, a more likely possibility is that both native and non-native speakers are susceptible to the stimulation, but given that the English language system is more robust and entrenched in native English speakers, a greater degree of stimulation (e.g., repetitive tDCS) and a larger sample size will be required to show a significant effect for native speakers.

In terms of moving forward our understanding of the neural basis of creativity, these results suggest that we need to be cautious about comparing neural results from different creativity tasks. The shortcomings of this approach are

highlighted in a recent review where it is argued that studies to date have yielded sets of conflicting and fragmented results regarding the neural basis of creative thought processes (Dietrich & Kanso, 2010). The results differ with respect to both involvement of hemispheres (left, right, bilateral) and specific cortical regions (Bengtsson, Csíkszentmihályi, & Ullén, 2007; Bhattacharya & Petsche, 2005; Bowden & Jung-Beeman, 2003; Falcone & Loder, 1984; Fink et al., 2009; Friedman & Förster, 2005; Jung-Beeman et al., 2004; Kounios et al., 2006; Razumnikova, 2007; Weinstein & Graves, 2002).

Our results suggest one obvious reason for this discrepancy: the studies use a wide range of tasks (encompassing insight tasks, divergent thinking tasks, and other open-ended tasks), and these tasks often involve different modalities (linguistic, visual spatial, numerical). Consequently, the differential involvement of hemispheres and cortical regions found across these studies may simply reflect differences in specific task and modality requirements. Perhaps the conclusion to be drawn here is similar to the one drawn in the neural basis of logical reasoning literature (Goel, 2007)—that there may be no notion of creativity independent of specific tasks and modalities. This suggests a program of study where we search for dissociations in systems involved in creative thought processes based upon task and modality demands, rather than assuming a single mechanism, and arguing about whether it is in the right hemisphere, left hemisphere, temporal lobes, frontal lobes, and so forth.

It is worth noting that this is not the only possible conclusion one can arrive at. Gabora (2010) provides a theoretical account whereby the unifying thread of creative thought processes are not to be associated with specific anatomical structures, but are a function of simultaneous activation of cell assemblies that have not fired in synchrony before, resulting in the conscious experience of new connections and perspectives. This is a very interesting alternative explanation, though it may run counter to some basic assumptions underlying neuropsychology (Caramazza, 1984; Goel, 2005; Shallice, 1988; Shallice & Cooper, 2011).

Finally, in terms of applications, the fact that it is possible to show an actual enhancement in the insight task condition suggests that building a “thinking cap” or “creativity cap” using high definition tDCS, which modulates performance in certain types of cognitive tasks by selectively depolarizing and hyperpolarizing different brain areas, may no longer be confined to the realm of science fiction.

NOTES

1 Gabora (2010) provides an interesting account based on the structure of semantic memory and “defocused attention” mechanisms that purports to account for both divergent thinking problems and insight problems.

- 2 There may be overlapping properties even within well-studied creativity tasks. For example, the Remote Associates Task was developed by Mednick (1962) as a divergent thinking task. A number of researchers believe that it also has an insight component and use it as an insight task (Jung-Beeman et al., 2004).
- 3 The Remote Associates Task involves presenting participants with three words (e.g., blue, Swiss, cottage) and asking them to generate a fourth word that relates the three (“cheese” in the above example: blue cheese, Swiss cheese, and cottage cheese).

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APPENDIX A: RIDDLE/INSIGHT TASK SETS

SET 1

1A. Why are 1992 pound coins worth more than 1991 pound coins?

Solution: *1,992 is more than 1,991.*

1B. Professor Bumble, who is getting on in years, is growing absent minded. On the way to a lecture one day, he went through a red light and turned down a one-way street in the wrong direction. A policeman observed the entire scene but did nothing about it. How could Professor Bumble get away with such behavior?

Solution: *He was walking.*

1C. A window washer was cleaning the windows of a high rise building when he slipped and fell off a 60-foot ladder onto the concrete sidewalk below. Incredibly, he did not injure himself in any way. How was this possible?

Solution: *He fell off the first rung of the ladder.*

1D. Paul is carrying a pillow case full of feathers. Mark is carrying three pillow cases the same size as Paul's, yet Mark's load is lighter. How can this be?

Solution: *Mark's pillowcases are empty.*

1E. A woman shoots her husband, then holds him under water for five minutes. Finally, she hangs him. Five minutes later they enjoy a wonderful dinner together. How can this be?

Solution: *She took a photo of him and developed it in the dark room.*

SET 2

2A. A man in a small town married 20 different women of the same town. All are still living and he never divorced. Polygamy is unlawful but he has broken no law. How can that be?

Solution: *He was the minister presiding over the wedding ceremony.*

2B. Captain Scott was out for a walk when it started to rain. He did not have an umbrella and he wasn't wearing a hat. His clothes were soaked yet not a hair on his head got wet. How could this happen?

Solution: *He is bald.*

2C. A father and his son get in a car accident. The father is sent to one hospital, and the son is sent to another. When the doctor comes in to operate on the son, the doctor says, "I cannot operate on him. He is my son." How can that be?

Solution: *The doctor is the mother.*

2D. A magician claimed to be able to throw a ping-pong ball so that it would go a short distance, come to a dead stop, and then reverse itself. He also added that he would not bounce the ball against any object or tie anything to it. How could he perform this feat?

Solution: *He threw it up in the air.*

2E. What has a neck and no head, two arms but no hands?

Solution: *A shirt, sweater, jacket.*

SET 3

3A. A man is reading a book when the lights go off, but even though the room is pitch dark, the man goes on reading. How?

Solution: *The man is blind and is reading Braille.*

3B. Two mothers and two daughters were fishing. They managed to catch one big fish, one small fish, and one fat fish. Since only three fish were caught, how is it possible that each woman had her own fish?

Solution: *There are only three women—(grandmother, mother, and daughter)—the mother is a daughter too.*

3C. Professor Gray was driving along in her old car when suddenly it shifted gears by itself. She paid no attention and kept on driving. Why wasn't she concerned?

Solution: *The car is an automatic.*

3D. I was framed, yet I didn't commit a crime, and the person who framed me committed no crime. How is this possible?

Solution: *I am a picture, and I was put in a picture frame.*

3E. A completely black dog was strolling down Main Street during a total blackout affecting the entire town. Not a single streetlight had been on for hours. Just as the dog was crossing the middle line, a Buick Skylark with two broken headlights speedily approached his position, but managed to swerve out of the way just in time. How could the driver have possibly seen the dog to swerve in time?

Solution: *It was during the day.*

SET 4

4A. Someone walked for 20 minutes on the surface of a lake without sinking but without any form of flotation aid. How?

Solution: *The lake is frozen.*

4B. Marsha and Marjorie were born on the same day of the same month of the same year to the same mother and the same father—yet they are not twins. How is that possible?

Solution: *They are triplets.*

4C. One morning a woman's earring fell into a cup that was filled with coffee, yet her earring did not get wet. How could this be?

Solution: *The earring fell into coffee grounds.*

4D. While on safari in the wild jungles of Africa, Professor White woke one morning and felt something in the back pocket of her shorts. It had a head and a tail but no legs. When White got up she could feel it move inside her pocket. White, however, showed little concern and went about her morning rituals. Why such a casual attitude toward the thing in her pocket?

Solution: *It was a coin.*

4E. Our basketball team won a game last week by a score of 73-49, and yet not even one man on our team scored as much as a single point. How is that possible?

Solution: *It was a woman's team.*

SET 5—SPARE

5A. When a bird flies over the ocean, a part of the body touches the water but doesn't get wet. What part is it?

Solution: *The shadow.*

5B. What is at the beginning of eternity, end of space and time, is the beginning to every end and the end to every place?

Solution: *The letter "e."*

5C. A man drove all the way across the United States without knowing he had a flat tire. Explain.

Solution: *The spare tire was flat.*

5D. What seven-letter word has hundreds of letters in it?

Solution: *Mailbox.*

5E. The legendary runner Flash Fleetfoot was so fast that his friends said he could turn off the light switch and jump into bed before the room got dark. On one occasion Flash proved he could do it. How?

Solution: *He went to bed during the day*