Brain and Cognition 71 (2009) 204–214

Contents lists available at ScienceDirect

Brain and Cognition

journal homepage: www.elsevier.com/locate/b&c

Influence of handedness and bilateral eye movements on creativity

Elizabeth R. Shobe[a,*], Nicholas M. Ross[b], Jessica I. Fleck[a]

[a] The Richard Stockton College of New Jersey, Pomona, New Jersey, United States
[b] Rutgers University, New Brunswick, New Jersey, United States

ARTICLE INFO

Article history:
Accepted 27 August 2009
Available online 2 October 2009

Keywords:
Handedness
Creativity
Eye movements
Laterality
Hemisphere
Alternate uses
Divergent thinking
Brain
Cognition
Bilateral

ABSTRACT

We investigated the effects of increased inter-hemispheric interaction (IHI) on five creativity dimensions (appropriateness, detail, categorical distinctiveness, fluency, and originality) of the Alternate Uses Task. Two methods were used to indicate degree of IHI. Trait IHI was indicated by individual differences in handedness, mixed-handers showing greater IHI than strong-handers. State IHI was directly manipulated by central (control group) and bilateral viewing conditions of a 30 s eye movement task (EM). Results indicate significantly higher creativity for mixed-handers, as compared to strong-handers, for all five sub-scores separately and linearly combined. Bilateral EM increased originality and categorical distinctiveness (i.e., flexibility) of strong-handers, but had no effect on mixed-handers. Strong-handers in the bilateral EM group were not different from mixed-handers. Additionally, the bilateral EM effect on strong-handers had different durations for originality (up to 7–9 min) and categorical distinctiveness (up to 3 min). The results suggest that greater IHI can facilitate creativity of strong-handers, but that the characteristically higher IHI of mixed-handers was unaffected by the bilateral EM manipulation.

1. Introduction

The creative process, although epitomized by a broad spectrum of brilliant individuals ranging from Renaissance man, Leonardo da Vinci to Oscar-winning actor, Christopher Walken, is a process employed by everyone in their daily endeavors. Despite an extensive literature on creativity (for reviews see Finke, Ward, & Smith, 1992; Runco, 2006; Simonton, 2004; Sternberg, 1998), the creative process is not yet fully understood. However, researchers have begun to identify general neural substrates that appear to mediate the creative process, with compelling physiological evidence suggesting that creativity is facilitated by interaction between the right and left cerebral hemispheres. Our current study tested the hypothesis that greater inter-hemispheric interaction (IHI) will improve performance on the Alternate Uses Test, a divergent thinking creativity test. Specifically, we investigated if individual differences in trait IHI (indicated by strength of handedness) and experimental manipulation of state IHI (using a bilateral eye movement task) would increase creativity.

Several lines of research suggest that the right hemisphere (RH) is fundamental to creative thinking. For example, increased RH activity has been observed in association with solving convergent problems (Jung-Beeman et al., 2004), divergent thinking by imagining and writing a creative story (Kwiatkowski, 2002), and in highly creative individuals (Grabner, Fink, & Neubauer, 2007; Jaušovec & Jaušovec, 2000; Martindale, Hines, Mitchell, & Covello, 1984). Creativity tasks may also serve to preferentially activate the RH (Falcone & Loder, 1984; Harnad, 1972) or prime the RH to produce an advantage for other RH lateralized tasks (Abeare, 2005; Weinstein & Graves, 2002). Solution primes are also better utilized by the RH for solving creative problems (Beeman & Bowden, 2000, experiment 1; Bowden & Beeman, 1998, experiment 1, Bowden & Jung-Beeman, 2003); and the RH has an advantage for recognizing insight solutions in visual half-field presentations (Beeman & Bowden, 2000, experiment 2). Additionally, the coincidence of a dysfunctional left hemisphere in schizophrenics with hyper or distorted qualities of divergent thinking (magical ideation, loose association, ability to connect novel information) (Crow, 1997; Leonhard & Brugger, 1998), and the association between schizotypy and artistic abilities (Nettle, 2006; Preti & Vellante, 2007) or creativity scores (Folley & Park, 2005; Poreh, Whitman, & Ross, 1994) further point to RH involvement in creativity.

The RH role in the creative process may be its propensity toward a broad spread of activation to alternative meanings, alternative contexts, and/or weakly related concepts, relative to the LH inhibition of all but the most strongly related concepts (Beeman, 1998; Chiarello, 1988; Chiarello, Burgess, Richards, & Pollock, 1990; Chiarello, Richards, & Pollock, 1992; Ince & Christman, 2002). Bowden and Jung-Beeman (2003) suggest that this broad and diffuse nature of RH semantic activation is more conducive to recognizing the semantic overlap inherent in solutions to

* Corresponding author. Fax: +1 609 626 5559.
E-mail address: elizabeth.shobe@stockton.edu (E.R. Shobe).

0278-2626/$ - see front matter © 2009 Elsevier Inc. All rights reserved.
doi:10.1016/j.bandc.2009.08.017

compound remote associate problems. Further, the effects of solution priming last longer in the RH than they do in the LH (Beeman & Bowden, 2000; Bowden & Beeman, 1998), a pattern that has been demonstrated with lexical decision tasks (Chiarello et al., 1990; Koivisto, 1997). As such, the value of the RH in the creative process may be that its inherent processing style brings to the table a variety of choices and unique associates from which the creative response can emerge.

However, the RH does not appear to operate independently of the LH in the creative process, whereby any argument for the RH as the seat of creativity is likely to be false. Indeed, a growing body of evidence suggests that the neurological contributions to the creative process are better qualified as a collaborative effort or interaction between the two hemispheres. Inter-hemispheric interaction (IHI) has implications for several higher order cognitive processes, such as belief updating and semantic processing. Ramachandran (1995) and Niebauer, Aselage, & Schutte, 2002) suggests that the LH is responsible for forming and maintaining rules and beliefs, whereas the RH is responsible for detecting anomalies and adjusting the belief structures of the LH accordingly. Ince and Christman (2002) suggest that the diffuse nature of the RH semantic network enables the more hierarchically organized LH to acquire new and alternate word meanings. Belief updating and semantic processing are routine, and both appear to result from a combination or interaction of efforts from both hemispheres. Further, both of these processes may also be important for the originality (i.e., ability to see alternative perspectives) and flexibility (i.e., ability to determine categorical distinctiveness) hallmarks of creativity.

In the context of a creative thinking task (e.g., alternate uses or remote associates), a creative response requires comprehension of the status quo use of an object or dominant semantic usage while simultaneously rejecting that status quo in favor of alternate meanings or object use. This notion is supported by Hoppe's (1988), Hoppe's (1989) observations that creativity results from the intersection of LH fixed rules and the diffuse possibilities offered by the RH (termed *hemispheric bisociation*). The hierarchical nature of LH semantic processing may be complimentary to the diffuse and broad RH by enabling rejection of common or un-creative responses, where the RH makes no such orderly distinctions. Further, because most creativity tasks include a verbal component (at the very least, a verbal response), the diffuse semantic activation of the RH must be restricted down to verbal responses, which are driven by the LH in the large majority of the population (Mckeever, Seitz, Krutsch, & Van Eys, 1995; Rasmussen & Milner, 1977). Beyond verbal or semantic contributions to the creative process, Starchenko, Bekhtereva, Pakhomov, and Medvedev (2003) observed activity in the left supramarginal and cingulated gyri during a divergent creativity task in which participants linked a sequence of words together. These areas are important for imagery (Knauff, Mulack, Kassubek, Salih, & Greenlee, 2002), planning during problem solving (Fincham, Carter, van Veen, Stenger, & Anderson, 2002), task switching (Sohn, Ursu, Anderson, Stenger, & Carter, 2000), and selective attention (Pardo, Pardo, Janer, & Raichle, 1990). In keeping with the notion of using routine processes in unique combinations to produce creative output, Dietrich (2004) suggests that the neural circuitry responsible for the noncreative processing of information is the same circuitry underlying creative proficiency in processing the same information.

The combination of processes from the LH and RH as essential for a creative response is underscored by the implication that creativity is not a singular process, but that it is moderated by various combinations of ordinary processes (Finke et al., 1992). Chavez-Eakle (2007 and McCallum & Glynn, 1979) also concluded that the bilateral and distributed processes for creativity reflect complex cognitive functions including imagery, memory, and novelty processing. Adding to this, Siebörger, Ferstl, and von Cramon (2007) had participants search for relationships between unrelated sentences (convergent task), and at the point when relationships were detected by participants, fMRI indicated activation in both LH and RH fusiform gyri (visual and spatial processing, abstraction) and dorsomedial pre-frontal cortex (executive functions). Observations that commissurotomy patients show deficits in creativity further demonstrate that communication between the cerebral hemispheres must be intact for creative thought (Hoppe, 1977; Hoppe, 1978; Hoppe, 1988; Hoppe & Bogen, 1977). Because the creative process appears to involve different processes that are distributed between the cerebral hemispheres, their coordination should facilitate a creative response (also suggested by Bogen, 2000; Hoppe & Kyle, 1990; Lezak, 1995; Miran & Miran, 1984). These distributed processes that also underlie more mundane thought suggests that the precise neural structures involved are less predictive of creativity than their functional combinations.

Others have made similar observations. Using EEG, Kounios et al. (2006) observed that a collaborative effort between the two hemispheres preceded the successful solving of compound remote-associates problems. In their study, LH (posterior temporal) activity appeared to coincide with preparation for solving problems using insight. Prior to discovering an insight solution there was activation of the anterior cingulate cortex, which serves as a mechanism for shifting cognitive/neurological control, followed by RH (anterior temporal) activity which almost immediately resulted in an insight solution. Jung-Beeman et al. (2004) also observed bilateral patterns of fMRI activity for insight solutions, greatest in the RH anterior superior temporal gyrus region, but a significant amount also in the LH medial frontal gyrus. Additional evidence for bilateral patterns of frontal lobe activity come from studies of cerebral blood flow and EEG during a divergent story creation task (Bekhtereva, Dan'ko, Starchenko, Pakhomov, & Medvedev, 2001; Bekhtereva et al., 2000), creation of visual images from two geometric forms (Sviderskaia, Antonov, & Butneva, 2007), and near infrared spectroscopy (NIRS) during a non-verbal alternate uses task (Folley & Park, 2005). Bilateral patterns have been observed during ambiguity resolution (Atchley, Keeney, & Burgess, 1999), generation of verbal associates (Razumnikova, 2007), and a verbal alternate uses task (Carlsson, Wendt, & Risberg, 2000). Carlsson et al. (2000) report bilateral patterns of frontal activity for highly creative individuals, but more unilateral activity for less creative individuals. The observation of creativity advantages associated with back and forth and/or simultaneous activation of the two hemispheres suggests that IHI may be necessary for both convergent and divergent creative thinking, and may be independent of the verbal or non-verbal nature of the task.

While the physiological evidence overwhelmingly supports IHI to be relevant to the creative process, such measures have been limited to time ordered observations of neural correlates in the creative process. As such, the question of whether IHI is necessary for creativity has not been experimentally investigated through manipulation of IHI, and is the basis for our study. Group differences in IHI have been studied using two methods, but none have specifically examined creativity. One method that has been used is the comparison between individuals with strong and mixed (i.e., ambidextrous and inconsistent) hand preferences, where mixed-handers exhibit greater amounts of IHI than their strong-handed counterparts. The connection between handedness and IHI is an assumption supported by a considerable amount of neurological evidence (e.g., Clarke & Zaidel, 1994; Cowell, Kertesz, & Denenberg, 1993; Habib et al., 1991; Witelson & Goldsmith, 1991) and behavioral evidence (e.g., Cherbuin & Brinkman, 2006a; Cherbuin & Brinkman, 2006b; Propper & Christman, 2004; for reviews, see Christman, 1995; Niebauer & Garvey, 2004; Niebauer et al., 2002).

For example, Christman (2001) observed that left-handers, a more mixed-handed group than right handers (Bryden & Steenhuis, 1991; Christman, 1995; Hellige, 1993), exhibited greater Stroop interference and greater local–global interference, which was interpreted as reflecting greater interaction between LH-based verbal/local processing and RH-based chromatic/global processing. Further, Propper, Christman, and Phaneuf (2005) observed an advantage for mixed-handers over strong-handers on episodic retrieval tasks, converging on physiological research implicating bilateral patterns of activity for enhanced performance on episodic memory tasks (Platel, Baron, Desgranges, Bernard, & Eustache, 2003; Tulving, Kapur, Craik, Moscovitch, & Houle, 1994). Mixed-handers also have an advantage over strong-handers for other memory tasks that would benefit from increased IHI (e.g., source memory), but show no such advantage on memory tasks that would not require IHI (e.g., face recognition) (Lyle, McCabe, & Roediger, 2008). While creativity and degree of handedness has not been directly studied (although there are some studies that have examined direction of handedness and creativity), mixed-handedness has been associated with greater magical ideation (Barnett & Corballis, 2002), and artists have a higher incidence of sinistrality and mixed-handedness (Preti & Vellante, 2007). Further, mixed-handers generate more alternate-endings to scenarios (i.e., counterfactual thought) than do strong-handers (Jasper, Barry, & Christman, 2008), and the frontal cortex of both hemispheres contribute to counterfactual thinking tasks (Gomez Beldarrain, Garcia-Monco, Astigarraga, Gonzalez, & Grafman, 2005). If IHI is crucial to the creativity process, then it is plausible to suggest that mixed-handers would demonstrate higher creativity than strong-handers. However, it is important to note that handedness is a stable characteristic of individuals and cannot be directly manipulated.

An alternative approach to the study of IHI is the direct manipulation of IHI through the use of horizontal bilateral eye movements (EMs) (see Charlton, Bakan, & Moretti, 1989; Propper & Christman, 2008 for reviews of supporting behavioral and neurophysiological evidence). Lateral eye movements have been associated with activation of the contralateral hemisphere (Bakan & Svorad, 1969), so it is reasonable to suggest that bilateral EMs increase bilateral hemispheric activation, promoting inter-hemispheric interaction (Christman & Garvey, 2001; Christman, Garvey, Propper, & Phaneuf, 2003; Rosano et al., 2002). Using EEG to measure coherence between the cerebral hemispheres, Propper, Pierce, Geisler, Christman, and Bellorado (2007) observed that bilateral EMs were associated with changes in inter-hemispheric coherence in the anterior pre-frontal cortex. Although the nature of these changes was not clear from their study, they do show an effect of bilateral EMs on inter-hemispheric processes. Again using an episodic memory task, Christman, Propper, and Dion (2004) and Brunye, Mahoney, Augustyn, & Taylor, 2009) provided converging evidence that bilateral EMs increase IHI. They observed that both mixed-handers and participants who did a 30 s bilateral EM task both showed an advantages for episodic memory. While there are no direct observations of the precise neurological effects of bilateral EMs on IHI or bi-hemispheric activation, a substantial amount of behavioral and physiological evidence suggests that mixed-handedness and bilateral EMs are associated with increased IHI. One difference between them being that handedness is a stable individual difference trait, whereas bilateral EM is a manipulated state.

In the current study, we investigated whether an increase in IHI will lead to greater creativity, as indicated by performance on an adaptation of the Alternate Uses Test used to measure divergent thinking. Because handedness has been suggested to be an indication of an individual's trait IHI, one hypothesis was that mixed-handers will demonstrate higher creativity (specifically, higher originality and flexibility scores) than strong-handers. A second hypothesis tested whether inducing IHI through bilateral EMs will increase creativity relative to control participants using a pre-and post-test design. A pre-/post-test design was specifically chosen to determine changes in creativity following the EM task, and to test a third hypothesis that strong-handers may be the only participants to benefit from the bilateral EM task. In line with the Lyle, Logan, and Roediger (2008) observations of a more pronounced effect for strong-handers, it is predicted that mixed-handers may experience a pseudo-ceiling effect because of high trait levels of IHI making them less susceptible to the bilateral EM manipulation.

We chose to measure creativity using an adaptation of Guilford's (1950) Alternate Uses Test (i.e., Christensen, Guilford, Merrifield, & Wilson, 1960) for several reasons. The Alternate Uses Test is often utilized for the scientific study of creativity in the normal population (as opposed to creative extremes) and is parsed into a number of trials where individuals are asked to generate as many uses as possible for household items (e.g., paper-clip, brick, newspaper). The alternate uses task is generally regarded as a measure divergent thinking, requiring participants to explore several different perspectives, producing an array of potential answers, situated on a gradient of utility. We felt that this type of task may optimize the recruitment of LH and RH processes because the test reflects the creativity 'process' rather than a self-report inventory, allowing us to measure creative reasoning (Runco, 2004). We adopted the scoring method from Chamorro-Premuzic (2006), who measured five dimensions of creativity: fluency, originality, elaboration, flexibility (categorical distinctiveness) and appropriateness. This enabled us to complete analyses of the individual sub-components, particularly originality and flexibility, which are hallmarks of creative output (Runco, 2008). In addition to the Alternate Uses Test being a commonly-used measure, it was chosen on the basis that Martindale (1999) suggests it to be a pure measure of the novelty and utility associated with creativity.

Lastly, the individual and timed trials that comprise the Alternate Uses Test were ideally suited to explore the duration of the bilateral EM effect. Because the bilateral EM effect on IHI is most likely a transient state, we questioned whether the duration was long enough to produce noticeable benefits on open-ended or lengthy creative tests. In the current study, the Alternate Uses post-test consisted of 15 trials (one item per trial) and participants were allotted 60 s to write as many alternate uses that came to mind during each trial. The duration of the episodic memory task reported by Christman et al. (2004) was 90 s, which was suitable to observe a sustained EM effect, but to date, there is no empirical research that outlines the length of this effect. The Alternate Uses Test enabled us to examine creativity following the bilateral EM task in increments up to 15 min. Accordingly, the current study had no *a priori* predictions regarding the duration of the effect.

2. Method

2.1. Participants

Sixty five undergraduate college students participated for extra or required credit in currently enrolled courses. They were obtained through an online psychology lab website (SONA, Inc.) available only to students at the college through individual participant accounts. Three participants were discarded from analyses (one for insufficient data and two for noncompliance with instructions). The remaining 62 participants consisted of 13 males and 49 females, ranging in age from 18 to 56 years ($M = 22.64$, SD = 6.43). Participants were randomly assigned to the bilateral EM group ($n = 32$) or the control group ($n = 30$). Following the lead of Christman et al. (2004) who used a median split of scores on the

Edinburgh Handedness Inventory (EHI) to determine strength of handedness, the current Me = 77.5 was used. Because the EHI is scored in increments of five, participants' absolute scores of 80 and higher were considered to be strong handed and absolute scores of 75 and lower were considered to be mixed-handers. The current study consisted of 30 mixed-handers and 32 strong-handers (only one strongly left-handed, score = −100).

2.2. Materials/apparatus

An adaptation of the Alternate Uses Test (Chamorro-Premuzic, 2006) was used to measure creativity. This adaptation consisted of 20 common items (e.g. paper-clip, pencil, shoe, for full list see Appendix A). We used 15 items from the original Alternate Uses Test (Christensen et al., 1960) and five from a common word bank (Snodgrass & Vanderwart, 1980). Each item was centered at the top of an 8.5″ × 11″ sheet of white computer paper, typed in 16 pt. Times New Roman font. The common use appeared in parentheses next to each item. Pre-tests items included five items printed in a booklet with a title page that displayed the printed instructions in 16 pt. Times New Roman font. Post-test items included the remaining 15 items printed in a separate booklet, also with a title page containing the printed instructions. To avoid any order effects that might be imposed by any specific item, two separate versions of the pre-test and post-test were created, and items were randomly ordered within each.

Responses on the Alternate Uses Test were scored on five different sub-scores: (a) fluency, indicated by the total number of uses listed per item (regardless of 'quality' or appropriateness); (b) originality, indicated by the number of responses provided by 0–5% pf participants (3 points), 6–10% (2 points) or 11–15% (1 point) of all participants in the sample; (c) amount of detail or elaboration provided for each use (on a 0–5 point scale); (d) flexibility or the number of 'categorically' distinct answers (1 point for each distinct 'category' of uses); and (e) appropriateness or usefulness of responses (1 point for each 'appropriate' response). Scoring of participant responses was completed by a rater blind to the treatment conditions and trained in using and scoring the Alternate Uses Test. The scoring procedure resulted in five sub-scores for each participant, where their points on each were tallied.

Handedness was measured using a modification of the Edinburgh Handedness Inventory (Oldfield, 1971), an instrument shown to be reliable and well-validated (Bryden, 1977). Participants were asked to indicate their preference (always, usually, no preference) of hand use for 10 activities from the Edinburgh Handedness Inventory (e.g., writing, drawing, throwing). Handedness scores for each participant ranged from 100 (perfectly right-handed) to −100 (perfectly left-handed).

The visual stimuli used for both the bilateral EM task and control task were presented on an Apple G4 computer, using MacLaboratory Reaction Time v.3.0.2 to control presentation of the stimuli. In the bilateral EM condition, participants received a Moving Circle task similar to Christman et al. (2004). The Moving Circle task requires participants to follow a colored circle (approximately 4 degrees of visual angle in diameter) on a white background of the computer screen as it appears sequentially on the left and right sides of the display. The circle changed positions every 500 ms producing two eye movements per second, one left-looking and one right-looking. The dots' appearances were separated by 27 degrees of visual angle. The color changed each time the circle appeared on the screen pseudo-randomly such that no color appeared twice in succession. This task lasted 30 s and participants were required to place their head in a chin rest for the duration of the task to ensure that the eyes, and not the head, were moving to follow the dot. The Moving Circle task deviates from Christman et al. (2004) in that their circles were black, whereas the current task used color circles (green, blue, yellow, magenta, cyan and red). This was done to be consistent with the control task used by us in this study and by Christman et al. (2004).

Control condition participants received a Central Circle task identical to that found in Christman et al. (2004). This task differed from the Moving Circle task in that the color dot was always presented centrally. This task offers visual stimulation in the absence of eye movements. Otherwise, the parameters of the Moving Circle and Central Circle tasks were identical.

2.3. Procedure

All participants were tested individually. Following their written informed consent, participants completed the Alternate Uses pre-test, and were randomly assigned to use either Form A or Form B. Participants were orally instructed to print as many uses as they could think of, other than the common use printed in parentheses. Participants were allotted 1 min per item (one item per trial). At the end of each trial, participants were instructed to stop and wait for instructions before turning the page to begin the next trial.

Immediately following the pre-test trials, participants moved their chairs to be in front of the computer and placed their chin in a chin rest. Participants were randomly assigned to either the bilateral EM condition, where they completed the Moving Circle task, or the control condition, where they completed the Central Circle task. Participants who completed the Moving Circle task were instructed to follow the moving circle with their gaze for the next 30 s until the stimuli disappear. Participants who completed the Central Circle task were instructed to watch the display for the next 30 s until the stimuli disappear. Compliance with these instructions was closely monitored by one of the authors. This procedure is identical to Christman et al. (2004).

After completing the circle task, all participants were given either Form A or Form B of the Alternate Uses post-test, and followed the exact same procedure used for the pre-test. The Alternate Uses post-test was followed by the Edinburgh Handedness Inventory. At the conclusion of each session, participants were debriefed and informed of the true purposes of the study. They were provided with the researcher's contact information for any further questions pertaining to the project (no one called).

3. Results

3.1. Preliminary findings

To determine if the bilateral EM and control groups were equally creative prior to the manipulation, performance on the pre-test were submitted to an independent samples *t*-test. Due to random assignment, no differences were expected and in fact none were found for any of the five creativity sub-scores, all Fs < 1. Additionally, multivariate tests revealed no differences between Form A and B of the pre-test or post-tests, and so these groups were collapsed. The following analyses report multivariate findings, where the five sub-scores are linearly combined, and also univariate analyses, where each sub-score is a dependent variable. Participants' sub-scores were determined using the scoring procedure described above, and include responses across all trials. Both analyses are reported because they enabled finer-grained analyses of creativity measures.

3.2. Findings for linearly combined sub-scores of the Alternate Uses Test

To test the hypotheses that increased inter-hemispheric interaction (IHI; indicated by handedness and bilateral EMs) lead to a creative advantage, and whether creativity was differentially affected pre-and post manipulation, the five sub-scores of the Alternate Uses Test (fluency, detail, originality, categorical distinctiveness and appropriateness), were submitted to a 2 (Condition: control, bilateral EM) × 2 (Handedness: mixed, strong) × (2) (Test: pre, post) mixed factorial MANOVA. Multivariate tests revealed a significant main effect for Handedness (Wilk's Λ = .779, $F(5, 54) = 3.06$, $p = .017$, ($\eta_p^2 = .221$) and Test (Wilk's Λ = .735, $F(5, 54) = 3.89$, $p = .004$, ($\eta_p^2 = .265$) when the dependent variables are linearly combined across all trials. No main effect for Condition (Wilk's Λ = .959, $F < 1$), or interactions of Handedness × Test (Wilk's Λ = .907, $F < 1$), Handedness × Condition (Wilk's Λ = .978, $F < 1$), Test × Condition (Wilk's Λ = .947, $F < 1$), or Handedness × Condition × Test (Wilk's Λ = .927, $F < 1$) were observed for the linearly combined sub-scores. Univariate ANOVA's also revealed no significant differences for Test for the five sub-scores, suggesting that the main effect in the multivariate tests of pre vs. post-test observed to be an overall practice effect that is not specific to any of the individual sub-scores.

3.3. Handedness findings for individual sub-scores of the Alternate Uses Test (post circle task)

The analyses presented in this section are based on participants' responses over all 15 trials of the Alternate Uses Task for each sub-score. Univariate tests indicate that mixed-handers showed greater fluency ($M = 3.09$, SE = .19) than strong-handers ($M = 2.44$, SE = .18), $F(1, 58) = 6.15$, $p = .016$, ($\eta_p^2 = .096$); mixed-handers (M = 2.45, SE = .142) showed greater categorical distinctiveness in their answers than strong-handers ($M = 1.67$, SE = .13), $F(1, 58)$ = 15.576, $p < .001$, ($\eta_p^2 = .21$); mixed-handers ($M = 2.70$, SE = .16) had more appropriate responses than strong-handers ($M = 1.84$, SE = .15), $F(1, 58) = 14.40$, $p < .001$, ($\eta_p^2 = .20$); and mixed-handers ($M = 3.35$, SE = .28) showed more originality than strong-handers ($M = 1.84$, SE = .27), $F(1, 58) = 13.80$, $p < .001$, ($\eta_p^2 = .19$). Mixed-handers ($M = 2.5$, SE = .13) were marginally higher than strong-handers ($M = 2.1$, SE = .18) on the detail sub-score, $F(1, 58) = 3.64$, $p = .06$, ($\eta_p^2 = .06$). These results support the hypothesis that mixed-handed individuals would demonstrate increased creativity on these individual scores than strong-handers.

Additionally, *a priori* tests suggest that the higher creativity of mixed-handers compared to strong-handers was driven solely by differences in the control group, but not the bilateral EM group. Comparisons between mixed and strong handers in the control group (no bilateral EM) revealed differences on all five sub-scores of creativity: fluency, $F(1, 28) = 4.2$, $p = .05$, $\eta_p^2 = .13$ ($M_{mixed} = 3.05$, SE = .24; $M_{strong} = 2.3$, SE = .26); detail, $F(1, 28) = 5.4$, $p = .03$, $\eta_p^2 = .16$ ($M_{mixed} = 2.54$, SE = .17; $M_{strong} = 1.95$, SE = .18); originality, $F(1, 28) = 9.14$, $p = .005$, $\eta_p^2 = .25$ ($M_{mixed} = 3.06$, SE = .39; $M_{strong} = 1.03$, SE = .42); categorical distinctiveness, $F(1, 28) = 9.46$, $p = .005$, $\eta_p^2 = .25$ ($M_{mixed} = 2.4$, SE = .20; $M_{strong} = 1.5$, SE = .21); and appropriateness, $F(1, 28) = 9.5$, $p = .005$, $\eta_p^2 = .25$ ($M_{mixed} = 2.75$, SE = .22; $M_{strong} = 1.75$, SE = .23).

These differences between strong and mixed-handers disappeared for the bilateral EM group for fluency ($F < 1$), detail ($F < 1$), originality [$F(1, 30) = 2.06$, $p = .16$], categorical distinctiveness [$F(1, 30) = 3.08$, $p = .09$], and appropriateness [$F(1, 30) = 2.6$, p = .12]. However, additional *a priori* tests directly comparing the control and bilateral EM conditions for mixed-handers revealed no differences for any sub-score (all F's < 1). For strong-handers, the only difference observed was that bilateral EM participants ($M = 2.41$, SE = .31) were significantly more original than control participants ($M = 1.03$, SE = .35), $F(1, 30) = 5.3$, $p = .02$, $\eta_p^2 = .15$; and marginally (but not significantly) higher in detail, $F(1, 30)$ = 3.55, $p = .06$. Fluency [$F(1, 30) = 2.03$, $p = .16$], categorical distinctiveness [$F(1, 30) = 2.9$, $p = .09$], and appropriateness [$F(1, 30)$ = 2.14, $p = .15$] failed to reach significance. Taken together, these analyses indicate that the bilateral EM task facilitated creativity scores of strong-handers to levels not significantly different from mixed-handers, but did not have any discernible effect on mixed-handers. Further, the improvement of strong-handers was only enough for the EM group to be significantly better than the control group on originality, and perhaps, detail. Otherwise, the effect of bilateral EMs on fluency, categorical distinctiveness, and appropriateness, is slight in strong-handers (enough to raise their scores to be similar to mixed-handers, but not enough to be significantly different from their control group counterparts), and not at all present for mixed-handers (see Fig. 1 and Table 1). This supports the suggestion that mixed-handers may exhibit a pseudo-ceiling effect for IHI, where they are unaffected by the EM manipulation. Rather, it appears as though only strong-handers benefit from the EM manipulation.

3.4. Duration of EM effect

It is important to realize that the above analyses were conducted on the overall sub-scores of each participant, where all trials were combined to produce them. However, of particular interest to us was the duration of a bilateral EM effect, and was the main reason we chose to use a creativity test that was parsed into individual trials (15 in the post-test) of a short duration (60 s). Recall that Christman et al. observed IHI effects in weak-handers and also bilateral EM participants during a 90 s episodic retrieval task. Because we observed limited effects of bilateral EM on creativity, even for strong-handers, we wondered if the EM effect dissipated with increasing trials and would be stronger if we restricted analyses to the first few trials. To test this, the first three-trials were collapsed and compared to the collapsed mean for the last three-trials. The resulting means for each of the five sub-scores were submitted to a 2 (Handedness: strong, mixed) × 2 (Condition: control, bilateral EM) × (2) (Trial: Early, Late) mixed MANOVA. Main effects revealed higher scores for earlier than later Trials for detail, $F(1, 58) = 5.06$, $p = .03$, $\eta_p^2 = .08$ ($M_{early} = 2.48$, SE = .116; $M_{late} = 2.2$, SE = .10), and categorical distinctiveness, $F(1, 58) = 6.42$, $p = .01$, $\eta_p^2 = .10$ ($M_{early} = 2.18$, SE = .13; $M_{late} = 1.9$, SE = .11). Main effects of handedness revealed the same pattern reported above, where mixed-handers had higher scores on originality, $F(1, 58) = 5.85$, $p = .02$, $\eta_p^2 = .09$ ($M_{mixed} = 2.95$, SE = .30; $M_{strong} = 1.95$, SE = .29); categorical distinctiveness, $F(1, 58) = 6.75$, $p = .01$, $\eta_p^2 = .10$ ($M_{mixed} = 2.33$, SE = .15; $M_{strong} = 1.78$, SE = .15); and appropriateness, $F(1, 58) = 6.52$, $p = .01$, $\eta_p^2 = .10$ (M_{mixed} = 2.74, SE = .18; $M_{strong} = 2.1$, SE = .17).

Also observed were significant Handedness × Condition × Trial interactions for originality, $F(1, 58) = 4.78$, $p = .03$, $\eta_p^2 = .08$, and categorical distinctiveness, $F(1, 58) = 5.27$, $p = .02$, $\eta_p^2 = .08$. Interaction contrasts revealed the nature of these comparisons to be that strong-handers in the bilateral EM condition showed significantly higher creativity for early trials than late trials, for both originality, $F(1, 17) = 12.12$, $p = .003$, $\eta_p^2 = .42$ ($M_{early} = 3.09$, SE = .49; $M_{late} = 1.9$, SE = .33), and categorical distinctiveness, $F(1, 17)$ = 12.47, $p = .003$, $\eta_p^2 = .42$ ($M_{early} = 2.22$, SE = .20; $M_{late} = 1.61$, SE = .18). Strong-handers in the control condition showed no differences between early and late trials for originality or categorical distinctiveness, Fs < 1. Mixed-handers in the bilateral EM condition showed no differences on early versus late trials for originality, $F < 1$, or categorical distinctiveness, $F(1, 13) = 2.9$, $p = .11$; and the same for mixed-handers in the control condition, originality $F = 1$ and categorical distinctiveness $F(1, 15) = 2.3$, $p = .15$. Conversely, in the early trials strong-handers in the bilateral EM condition had significantly higher originality scores than those in the control condition, $F(1, 30) = 5.78$, $p = .02$, $\eta_p^2 = .12$ ($M_{bilateralEM} = 3.09$, SE = .46; $M_{control} = 1.4$, SE = .53), and the same pattern was revealed

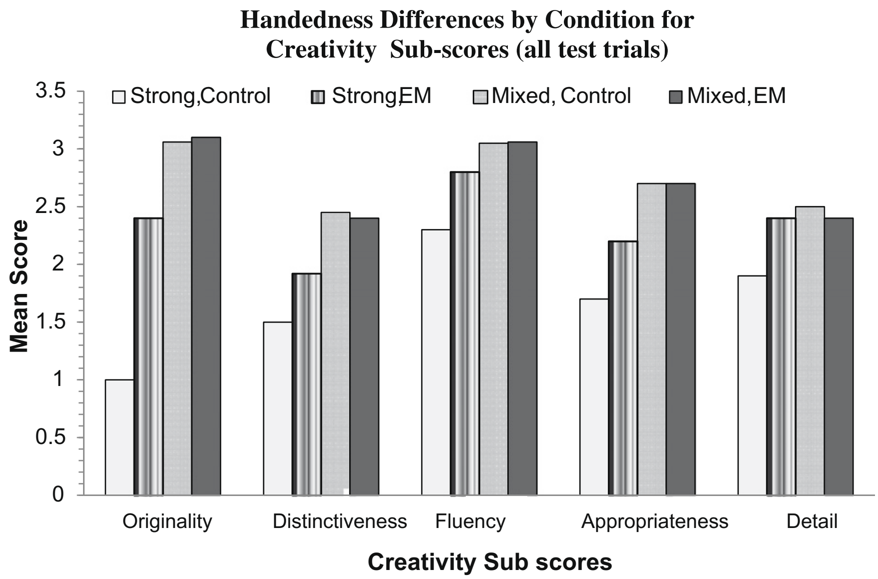

Fig. 1. Mixed-hander's performance did not differ for control and bilateral EM conditions. Mixed-handers, showed higher creativity than strong-handers in the control group, but no differences were observed in any sub-score between mixed and strong-handers in the bilateral EM group. Strong-handers in the control group had significantly lower scores than those in the bilateral EM group for originality and marginally for detail.

Table 1
Means for each sub-score (collapsed across trials) for strong and mixed-handers in the control and bilateral EM conditions.

	Strong handers		Mixed-handers	
	Control	Bilateral EM	Control	Bilateral EM
Originality	1.03	2.41	3.06	3.1
Distinctiveness	1.5	1.92	2.45	2.4
Fluency	2.3	2.8	3.05	3.06
Appropriateness	1.75	2.2	2.75	2.7
Detail	1.95	2.4	2.54	2.4

for categorical distinctiveness, $F(1,30) = 4.71$, $p = .04$, $\eta_p^2 = .14$ ($M_{bilateralEM} = 2.22$, SE = .20; $M_{control} = 1.56$, SE = .23). No condition differences were observed for early trials of mixed-handers ($Fs < 1$), late trials of mixed-handers ($Fs < 1$), or late trials of strong-handers ($Fs \leqslant 1$).

Taken together, these results suggest that the bilateral EM manipulation affected originality and categorical distinctiveness scores of strong-handers during the early trials only, but this effect dissipated by the later trials. At this point, we wondered just how long the EM effect held for strong-handers in our study. To answer this, trials one through 15 were parsed into five groups of means in three-trial increments (Trials 1–3, Trials 4–6, Trials 7–9, Trials 10–12, and Trials 13–15), and were submitted to a one-way (Condition) MANOVA using the originality and categorical distinctiveness sub-scores at each of the five trial increments. Only originality and categorical distinctiveness sub-scores were used because these showed differences between the early and the late trials and these are the components of creativity addressed most frequently in prior research. Control and bilateral EM strong-handers differed for originality on Trials1–3 ("early" trials, reported above), Trials 4–6, $F(1,30) = 4.4$, $p = .04$, $\eta_p^2 = .13$ ($M_{control} = 1.33$, SE = .34, $M_{bilateral\ EM} = 2.43$, SE = .39), and for Trials 7–9, $F(1,30) = 4.1$, $p = .05$, $\eta_p^2 = .12$ ($M_{control} = .95$, SE = .43, $M_{bilateral\ EM} = 2.1$, SE = .38); but this difference disappeared for Trials 10–12, $F(1,30) = 2.0$, $p = .16$, and Trials 13–15 ("late", reported above) (see Fig. 2). Paired samples *t*-tests revealed no significant differences between Trials 1–3 and Trials 4–6, $t(17) = 1.53$, $p = .14$, or Trials 4–6 and Trials 7–9, $t(17) = 1.05$, $p = .31$, for strong-handers in the bilateral EM condi-

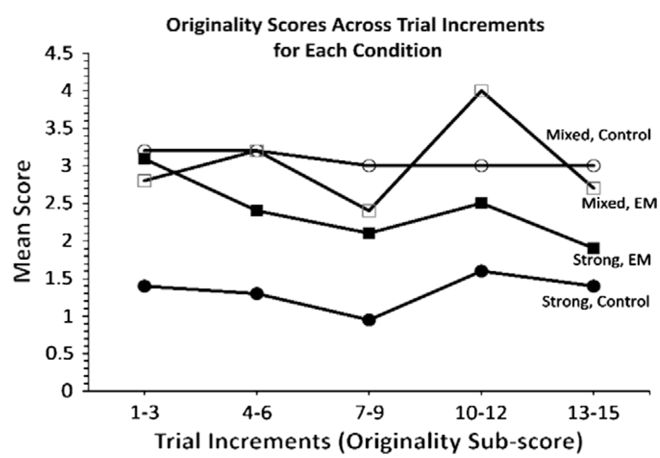

Fig. 2. Strong-handers in the bilateral EM group showed greater originality than those in the control group for trial increments 1–3, 4–6, and 7–9, but this difference disappeared for remaining trial increments.

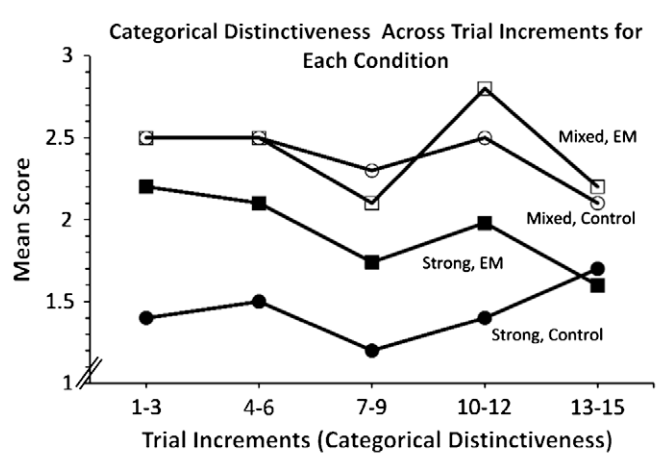

Fig. 3. Strong-handers in the bilateral EM group showed greater categorical distinctiveness than those in the control group for increments 1–3, and marginally for 4–6.

tion. However, for the categorical distinctiveness variable, only Trials 1–3 (reported above) reached significance, and Trials 4–6 were marginally significant, $F(1, 30) = 3.6$, $p = .06$. Trials 7–9 [$F(1, 30) = 2{,}4$, $p = .13$], 10–12 [$F(1, 30) = 2.5$, $p = .11$], and 13–15 (''late" trials, reported above) were not significant (see Fig. 3). This suggests that the effect of bilateral EM's on originality of strong-handers may last up to 9 min before it dissipates. But, the effects of bilateral EMs on categorical distinctiveness last at least 3 min and maybe up to 6 min (see Figs. 2 and 3, and Table 2).

While significant differences between control and bilateral EM conditions of strong-handers were only observed for the originality (up to trials 6–9) and categorical distinctiveness (up to trial 3) scores, additional analyses revealed general downward linear trends in the bilateral EM condition across the five trial increments for appropriateness $F(1, 17) = 8.03$, $p = .01$, originality, $F(1, 17) = 8.2$, $p = .008$, and categorical distinctiveness, $F(1, 17) = 12.30$, $p = .003$. These trends were not present for detail or fluency sub-scores of strong-handers in the bilateral EM condition. Further, these trends were not present for strong-handers in the control condition, or mixed-handers in the control or bilateral EM conditions (Fs < 1).

3.5. Additional findings

A MANOVA on demographic information collected (age, gender) revealed no effect of gender, Wilk's $\Lambda = .92$, $F(4, 57) = 1.25$, $p < .3$ on the linearly combined sub-scores. Univariate analyses indicate that males ($M = 2.48$, SE = .232) outperformed females ($M = 1.96$, SE = .12) on the categorical distinctiveness variable, $F(1, 60) = 4.02$, $p = .05$, ($\eta_p^2 = .063$). Males ($M = 3.39$, SE = .434) also outperformed females ($M = 2.27$, SE = .224) on the originality variable, $F(1, 60) = 5.24$, $p = .03$, ($\eta_p^2 = .08$), but the unplanned, exploratory nature of these gender comparisons necessitated a Bonferroni correction (adjusted to $\alpha = .01$) to control the Type 1 error probability (Keppel & Wickens, 2004). Using this adjusted α it appears that the gender differences are spurious, and not significant. Pearson product moment correlation analyses on age and the five creativity sub-scores revealed that age and categorical distinctiveness were strongly correlated, $r(59) = .25$, $p = .05$ as were age and appropriateness, $r(59) = .28$, $p < .05$, and age and originality, $r(59) = .30$, $p = .02$. No age differences were observed between EM groups, $t(59) = .60$, $p = .550$, or Handedness groups, $t(59) = 1.58$, $p = .121$.

4. Discussion

We examined whether an increase in inter-hemispheric interaction would lead to greater creativity on the Alternate Uses Test. Three main hypotheses were explored. First, we hypothesized that the characteristically higher IHI of mixed-handers would result in higher creativity than strong-handers. Comparisons between mixed and strong-handers in the control condition supported this hypothesis for each of the creativity sub-scores. Second, we hypothesized that a 30 s bilateral EM task would increase creativity due its likelihood of increasing IHI, but that this effect may be limited to strong-handers. This was also supported by the observations that control group differences between mixed and strong-handers disappeared for the bilateral EM condition, no differences were observed between mixed-handers in the control and EM conditions, and strong-handers originality scores in the EM condition were elevated above their control counterparts. Similar findings have been reported by Lyle et al. (2008), who observed bilateral EM's to have no effect (or detrimental effects) on memory performance of mixed-handers. Our findings also suggest the presence of a bilateral EM effect restricted to strong-handers.

Our third hypotheses exploring the duration of the bilateral EM effect, suggested that the effect of bilateral eye movements weakens over a short period of time, and that the small differences between control and bilateral EM strong-handers in our first set of analyses was likely due to the inclusion of all 15 Alternate Uses trials. When trials were parsed into five three-trial (i.e., 3 min) increments, results indicated significant effects of the bilateral EM task on originality and categorical distinctiveness for strong-handers, as compared to the control condition. Further, the bilateral EM effects on originality and categorical distinctiveness were differentially affected by time. The EM effect on originality may last as long as seven to 9 min, but only one to 3 min (marginal significance suggests maybe, 4–6 min) for categorical distinctiveness. Again, no differences were observed for mixed-handers. Because the effect of the bilateral EM manipulation was time constrained, and also constrained to two components of creativity, this may explain why analyses on the combined 15 trials only reached significance for originality, and not categorical distinctiveness.

Importantly, the fact that fluency, detail, and appropriateness were unaffected by the bilateral EM manipulation does not indicate limited or marginal effects on creativity. Indeed, many researchers qualify originality (i.e., uniqueness) and categorical distinctiveness (i.e., flexibility) as the hallmarks of true creativity (Barron, 1968; Guilford, 1968; Guilford, 1982; Runco, 1985; Weisberg & Alba, 1981); fluency, detail, and appropriateness are less commonly included by researchers as creativity constructs. Further, fluency may actually be inversely related to creativity (Shemyakina & Dan'ko, 2004), and appropriateness is also an unlikely contributor (Runco, Illies, & Eisenman, 2005). As such, we are confident in concluding that bilateral EMs facilitate originality and categorical distinctiveness, and that these are the valid measures of creativity on divergent thinking tasks.

Interestingly, originality and categorical distinctiveness variables are not simply byproducts or necessary precursors of each other, but appear to be distinct processes. Runco and Okuda (1991) observed that an increase in categorical distinctiveness does not lead to an increase in originality or vice versa, suggesting them to be governed by independent processes. Our findings of the different effects of time on originality and categorical distinctiveness support these variables as distinct processes. This also suggests that the enhancing effects of bilateral EMs on these processes is not restricted to activation of a single 'creativity module' whose byproduct is both originality and categorical distinctiveness, but may have a more widespread effect on task relevant processes.

These findings for originality and categorical distinctiveness also support the physiological evidence that the IHI in creativity is due to an enhanced recruitment (or combination) of processes distributed between the LH and RH. Previous research indicates that both originality and categorical distinctiveness rely on bilateral contributions. For example, Razumnikova (2007) and Razumnikova &

Table 2
Means for originality and categorical distinctiveness sub-scores for each trial increment of strong and mixed-handers in the control and bilateral EM conditions.

	1–3	4–6	7–9	10–12	13–15
Originality					
Strong, control	1.4	1.33	.95	1.6	1.4
Strong, EM	3.09	2.43	2.1	2.5	1.9
Mixed, control	3.2	3.2	3	3	3
Mixed, EM	2.8	3.2	2.4	4	2.7
Distinctiveness					
Strong, control	1.56	1.5	1.2	1.4	1.7
Strong, EM	2.26	2.1	1.74	1.98	1.61
Mixed, control	2.5	2.5	4	2.5	2.1
Mixed, EM	2.5	2.5	2.3	2.8	2.1
			2.1		

Bryzgalov, 2006) observed bilateral EEG activity related to originality scores on a remote-associates task. The patterns observed by Razumnikova and colleagues also suggested that the hemispheres may be involved in different processes that contribute to originality such as, sustained attention, working memory, and diffuse activation of alternate word meanings and relationships. In addition, the creativity construct of categorical distinctiveness may also take advantage of specializations of the left and right hemispheres. The LH is particularly well-suited to categorical processing whereas the RH appears to be particularly well-suited to identifying multiple categorical memberships without the ability to distinguish the most relevant category (Chiarello & Richards, 1992; Chiarello et al., 1992; Ince & Christman, 2002). Thus, recruitment of LH abilities for identification of specific categories and RH abilities for multiple categories may give rise to a combined advantage for categorical distinctiveness scores. The findings of Bechtereva et al. (2004) also suggest that the LH is involved in categorical distinctiveness (termed *flexibility* by them). We suggest that originality and categorical distinctiveness responses were facilitated by IHI because they involve both LH and RH processes, and that IHI will have facilitative effects on any task that require bi-hemispheric contributions. This has also been proposed and supported by Lyle et al. (2008).

Even though originality and categorical distinctiveness do not appear to rely on the same processes or neural substrates, we are not suggesting that bilateral EMs result in a widespread, nonspecific activation of the cerebral hemispheres. Rather, our findings present evidence to the contrary because appropriateness, fluency, and detail, were largely unaffected by the bilateral EM manipulation. Although prior research is quite limited, these three response types may be more effectively processed unilaterally, within the LH or RH. Both verbal fluency (Baldo, Schwartz, Wilkins, & Dronkers, 2006) and appropriateness (Torrance & Horng, 1980) may be relatively restricted to LH processes. Conversely, ability to report visual details (Kessinger & Choi, 2009) and generate detailed visual images appears to be more reliant on RH processes (Gasparini et al., 2008; Sviderskaya, Taratynova, & Kozhedub, 2006), and may be analogous to the detail measure in our study. If bilateral EMs generated nonspecific activation of both hemispheres, our control group would have exhibited lower scores on each of these sub-scores. Our findings raise the possibility that only categorical distinctiveness and originality were affected by the EM manipulation because these behaviors can benefit from combined LH and RH processes, whereas appropriateness, detail, and fluency may be more reliant on unilateral processes.

Interestingly, it has been proposed that bilateral EMs may enable greater access to RH processes (Christman & Propper, in press), and our observation of a marginal detail advantage ($p = .06$) for bilateral EM participants does not undermine this possibility. But we also recognize that prior research on hemispheric asymmetries for generating details during visual imagery is sparse, thus limiting our speculations. Even still, if the bilateral EM task resulted in a generalized activation of both hemispheres, then strong-handers in our study should have (1) shown an improvement in the EM group over the controls for fluency, detail, and appropriateness; or (2) matched the mixed-handers. Instead, the mixed-handers outperformed them in the control and the bilateral EM groups, and so we are reasonably confident that the effect is task specific.

We also suspect that the IHI of mixed-handers is qualitatively different from the IHI facilitated by bilateral EMs because the manipulation did not raise all five sub-scores of strong-handers to levels equivalent with mixed-handers. While lengthy explanations of the mixed-handers advantage for detail, fluency, and appropriateness are beyond the scope of this paper, one possibility is simply that the basic anatomical difference in the size of the corpus callosum between strong and mixed-handers (Driesen & Raz, 1995; Habib et al., 1991; Witelson & Goldsmith, 1991) does not change following an EM task. The larger corpus callosum may give the mixed-handers a more generalized advantage on the measures we assessed. We readily acknowledge, however, that the literature is replete with inconsistent findings in support of a relationship between handedness and callosal size. The corpus callosum clearly facilitates transfer of information between the hemispheres, but it may also serve to reduce interference between the hemispheres. Recent work by Welcome et al. (2009) suggests that in mixed-handed males a larger corpus callosum may facilitate integration, but in mixed-handed females it may minimize interference. In our study, the participants were largely female, and so the mixed-handed advantage for detail, fluency, and appropriateness may reflect minimized interference for these supposed unilateral processes.

So, then, the question remains: What change does a bilateral EM task induce in the brain? Although the notion of a central executive in the mind may itself be overrated, we propose that bilateral eye movements serve to activate the neural substrates governing metacontrol processes that direct task specific processing (for review of metacontrol, see Hellige, 1995). Lohr et al. (2006) also suggest that metacontrol processes are the root of IHI. The work of Kounios et al. (2006) suggests the locus of this metacontrol mechanism for creativity may be the anterior cingulate cortex (ACC), but future neuroimaging research may be necessary to determine the relationship between bilateral EMs and the ACC.

Although we did not directly measure the effects of bilateral EMs on hemispheric activity, our findings add to a largely consistent set of behavioral and physiological findings from various laboratories indicating that bilateral EMs exert bilateral effects on hemispheric processing. Propper et al. (2007) directly observed bilateral changes in EEG coherence following the EM task. Our behavioral findings converge with and complement those of several others cited in the introduction (e.g., Christman et al., 2003; Lyle et al., 2008; Lyle et al., 2008) in supporting the hypothesis that bilateral EMs affect and/or enhance behaviors that rely on interhemispheric interaction. In our study, this effect was restricted to strong-handers, who have inherently less IHI than mixed-handers. Also supported was the hypothesis that individual differences in IHI affect performance on those creative processes that are distributed between the hemispheres, and therefore, should benefit from increased IHI. In addition, we provided behavioral evidence that aligns with previously reported physiological evidence that increased IHI leads to greater creativity. We also demonstrated that the effects of the bilateral EM are sustained beyond the duration of the circle task, and beyond the 90 s duration of the episodic memory task used by Christman et al. (2004). We also observed that the bilateral EM effect is temporally constrained, but that the precise time limit may be determined by the specific processes being affected.

Lastly, while the Alternate Uses Test is a commonly-used test of creativity it is not a complete measure of the creativity construct, but reflects one aspect of creativity. Our findings may not apply to more unique populations who are characterized as 'highly creative', nor can we conclude from our findings that the 30 s bilateral EM task will turn an average individual into an artist, poet, scientist, philosopher, actor, or sculptor. However, we certainly do propose that the 30 s bilateral EM task will result in a temporary increase in strong-hander's ability to think of creative uses for various household objects. More generally, creativity is not simply verbal or non-verbal, divergent or convergent, but a thought process composed of many different elements that show up in many different forms that no single task can entirely tap into. Even though the Alternate Uses Test we used required verbal inputs and responses, there is no evidence to suggest that the need for the verbal LH is the cause of bilateral activity. In addition to the bilateral patterns of activity reported by Folley and Park (2005) who utilized picture stimuli and allowed for spatial manipulation of those pictures before giving a verbal response, various creativity tasks have been associated with activity in LH frontal and tempero-parietal structures involved in spatial perception of objects (Jung-Beeman et al., 2004), planning and attention during the creative task (Bechtereva et al., 2004; Starchenko et al., 2003), and fantastical imagination which appears to be important for flexibility (i.e., categorical distinctiveness) (Bechtereva et al., 2004). Coupled with the findings of Brandimonte, Hitch, and Bishop (1992), who demonstrated that even participants engaged in a mental imagery task tend to re-code visual images into verbal codes, verbal and spatial/perceptual coding are probably present for both verbal and non-verbal creativity tasks. To date, there is little evidence to suggest that verbal and non-verbal creativity tasks are driven by different cognitive and neural components. As such, we recognize that our findings are specific to our task, but also raise the possibility that the underlying processes for other creativity tasks are similar.

Acknowledgement

Author would like to acknowledge Peter Gotta for his assistance with data entry.

Appendix A

Original Alternate Uses Items from Christensen et al. (1960):

- newspaper
- shoe
- button
- key
- wooden pencil
- automobile tire
- eyeglasses
- bar (was "cake" in original but was altered to be more easily understood) of soap
- barrel
- sock
- paper-clip
- comb
- table
- paper cup
- brick

Additional five items from common word bank (Snodgrass & Vanderwart, 1980):

- toothbrush, doorknob, hat, belt, book

References

Abeare, C. (2005). The hemispheric dynamics of semantic processing and creativity. *Dissertation Abstracts International: Section B: The Sciences and Engineering, 66*, 1705.

Atchley, R. A., Keeney, M., & Burgess, C. (1999). Cerebral hemispheric mechanisms linking ambiguous word meaning retrieval with subjects varying in verbal creativity. *Brain and Cognition, 32*, 282–284.

Bakan, P., & Svorad, D. (1969). Resting EEG alpha asymmetry of reflective lateral eye movements. *Nature, 223*, 975–976.

Baldo, J. V., Schwartz, S., Wilkins, D., & Dronkers, N. F. (2006). Role of frontal versus temporal cortex in verbal fluency as revealed by voxel-based lesion symptom mapping. *Journal of the International Neuropsychological Society, 12*, 896–900.

Barnett, K. J., & Corballis, M. C. (2002). Ambidexterity and magical ideation. *Laterality: Asymmetries of Body, Brain, and Cognition, 7*, 75–84.

Barron, F. (1968). *Creativity and personal freedom*. New York: Van Nostrand.

Bechtereva, N. P., Korotkov, A. D., Pakhomov, S. V., Roudas, M. S., Starchenko, M. G., & Medvedev, S. V. (2004). PET study of brain maintenance of verbal creative activity. *International Journal of Psychophysiology, 53*, 11–20.

Beeman, M. J. (1998). Coarse semantic coding and discourse comprehension. In M. Beeman & C. Chiarello (Eds.), *Right hemisphere language comprehension: Perspectives from cognitive neuroscience* (pp. 255–284). Mahwah, NJ: Erlbaum.

Beeman, M., & Bowden, E. (2000). The right hemisphere maintains solution-related activation for yet-to-be-solved problems. *Memory & Cognition, 28*, 1231–1241.

Bekhtereva, N. P., Dan'ko, S. G., Starchenko, M. G., Pakhomov, S. V., & Medvedev, S. V. (2001). Study of the brain organization of creativity: III. Brain activation assessed by the local cerebral blood flow and EEG. *Human Physiology, 27*, 390–397.

Bekhtereva, N. P., Starchenko, M. G., Klyucharev, V. A., Vorob'ev, V. A., Pakhomov, S. V., & Medvedev, S. V. (2000). Study of the brain organization of creativity: II. Positron-emission tomography data. *Human Physiology, 26*, 516–522.

Bogen, J. E. (2000). Split-brain basics: Relevance for the concept of one's other mind. *Journal of the American Academy of Psychoanalysis, 28*, 341–369.

Bowden, E. M., & Beeman, M. J. (1998). Getting the right idea: Semantic activation in the right hemisphere may help solve insight problems. *Psychological Science, 9*, 435–440.

Bowden, E. M., & Jung-Beeman, M. (2003). Aha! Insight experience correlates with solution activation in the right hemisphere. *Psychonomic Bulletin & Review, 10*, 730–737.

Brandimonte, M., Hitch, G., & Bishop, D. (1992). Verbal recoding of visual stimuli impairs mental image transformations. *Memory & Cognition, 20*, 449–455.

Brunye, T., Mahoney, C., Augustyn, J., & Taylor, H. (2009). Horizontal saccadic eye movements enhance the retrieval of landmark shape and location information. *Brain and Cognition, 70*, 279–288.

Bryden, M. P. (1977). Measuring handedness with questionnaires. *Neuropsychologia, 15*, 617–624.

Bryden, M., & Steenhuis, R. E. (1991). Issues in the assessment of handedness. In F. L. Kitterle (Ed.), *Cerebral laterality: Theory and research* (pp. 35–51). Hillsdale, NJ: Lawrence Erlbaum.

Carlsson, I., Wendt, P., & Risberg, J. (2000). On the neurobiology of creativity. Differences in frontal activity between high and low creative subjects. *Neuropsychologia, 38*, 873–885.

Chamorro-Premuzic, T. (2006). Creativity versus conscientiousness: Which is a better predictor of student performance? *Applied Cognitive Psychology, 20*, 521–531.

Charlton, S., Bakan, P., & Moretti, M. (1989). Conjugate lateral eye movements: A second look. *International Journal of Neuroscience, 48*, 1±18.

Chávez-Eakle, R. A. (2007). Creativity, DNA, and cerebral blood flow. In C. Martindale, P. Locher, & V. Petrov (Eds.), *Evolutionary and neurocognitive approaches to aesthetics, creativity and the arts* (pp. 209–224). Amityville, NY: Baywood Publishing Co.

Cherbuin, N., & Brinkman, C. (2006a). Efficiency of callosal transfer and hemispheric interaction. *Neuropsychology, 20*, 178–184.

Cherbuin, N., & Brinkman, C. (2006b). Hemispheric interactions are different in left-handed individuals. *Neuropsychology, 20*, 700–707.

Chiarello, C. (1988). Semantic priming in the intact brain: Separate roles for the right and left hemisperes? In C. Chiarello (Ed.), *Right hemisphere contributions to lexical semantics*. Heidelberg: Springer-Verlag.

Chiarello, C., Burgess, C., Richards, L., & Pollock, A. (1990). Semantic and associative priming in the cerebral hemispheres: Some words do, some words don't...sometimes, some places. *Brain and Language, 38*, 75–104.

Chiarello, C., & Richards, L. (1992). Another look at categorical priming in the cerebral hemispheres. *Neuropsychologia, 30*, 381–392.

Chiarello, C., Richards, L., & Pollock, A. (1992). Semantic additivity and semantic inhibition: Dissociable processes in the cerebral hemispheres? *Brain and Language, 42*, 52–76.

Christensen, P. A., Guilford, J. P., Merrifield, P. R., & Wilson, R. C. (1960). *Alternate uses*. Beverly Hills: Sheridan Psychological Services.

Christman, S. D. (1995). Independence versus integration of right and left hemispheric processing: Effects of handedness. In F. L. Kitterle (Ed.), *Hemispheric communication: Mechanisms and models* (pp. 231–253). Hillsdale, NJ: Lawrence Erlbaum.

Christman, S. D. (2001). Individual differences in Stroop and local–global processing: A possible role of interhemispheric integration. *Brain and Cognition, 45*, 97–118.

Christman, S., & Garvey, K. (2001). Bilateral eye movements reduce asymmetries in hemispheric activation. Paper presented at the 2001 EMDR international association conference, Austin, TX.

Christman, S., & Propper, R. (in press). An interhemispheric basis for episodic memory: Effects of handedness and bilateral eye movements. To appear in G. Davies & D. Wright (Eds.), *Current issues in applied memory*. London: Psychology Press.

Christman, S. D., Garvey, K. J., Propper, R. E., & Phaneuf, K. A. (2003). Bilateral eye movements enhance the retrieval of episodic memories. *Neuropsychology, 17*, 221–229.

Christman, S. D., Propper, R. E., & Dion, A. (2004). Increased Interhemispheric interaction is associated with decreased false memories in a verbal converging semantic associates paradigm. *Brain and Cognition, 56*, 313–319.

Clarke, J. M., & Zaidel, E. (1994). Anatomical–behavioral relationships: Corpus callosum morphometry and hemispheric specialization. *Behavioural Brain Research, 64*, 185–202.

Cowell, P. E., Kertesz, A., & Denenberg, V. H. (1993). Multiple dimensions of handedness and the human corpus callosum. *Neurology, 43*, 2353–2357.

Crow, T. J. (1997). Schizophrenia as failure of hemispheric dominance for language. *Trends in Neuroscience, 20*, 339–343.

Dietrich, A. (2004). The cognitive neuroscience of creativity. *Psychonomic Bulletin & Review, 11*, 1011–1026.

Driesen, N. R., & Raz, N. (1995). The influence of sex, age, and handedness on corpus callosum morphology: A metaanalysis. *Psychobiology, 23*, 240–247.

Falcone, D. J., & Loder, K. (1984). A modified lateral eye-movement measure, the right hemisphere and creativity. *Perceptual and Motor Skills, 58*, 823–830.

Fincham, J. M., Carter, C. S., van Veen, V., Stenger, V. A., & Anderson, J. R. (2002). Neural mechanisms of planning: A computational analysis using event-related fMRI. *Proceedings of the National Academy of Sciences, 99*, 3346–3351.

Finke, R. A., Ward, T. B., & Smith, S. M. (1992). *Creative cognition: Theory, research, and applications*. Cambridge, MA: MIT Press.

Folley, B., & Park, S. (2005). Verbal creativity and schizotypal personality in relation to prefrontal hemispheric laterality: A behavioral and near-infrared optical imaging study. *Schizophrenia Research, 80*, 271–282.

Gasparini, M., Hufty, A. M., Masciarelli, G., Ottaviani, D., Angeloni, U., Lenzi, G. L., et al. (2008). Contribution of right hemisphere to visual imagery: A visual working memory impairment? *Journal of the International Neuropsychological Society, 14*, 902–911.

Gomez Beldarrain, M., Garcia-Monco, J. C., Astigarraga, E., Gonzalez, A., & Grafman, J. (2005). Only spontaneous counterfactual thinking is impaired in patients with prefrontal cortex lesions. *Cognitive Brain Research, 24*, 723–726.

Grabner, R. H., Fink, A., & Neubauer, A. (2007). Brain correlates of self-rated originality ideas: Evidence from event-related power and phase-locking changes in the EEG. *Behavioral Neuroscience, 121*, 224–230.

Guilford, J. P. (1950). Creativity. *American Psychologist, 5*, 444–454.

Guilford, J. P. (1968). *Intelligence, creativity, and their educational implications*. San Diego, CA: Robert R. Knapp Publisher.

Guilford, J. P. (1982). Cognitive psychology's ambiguities: Some suggested remedies. *Psychological Review, 89*, 48–59.

Habib, M., Gayraud, D., Olivia, A., Regis, J., Salamon, G., & Khalil, R. (1991). Effects of handendess and sex on the morphology of the corpus callosum: A study with brain magnetic resonance imaging. *Brain and Cognition, 16*, 41–61.

Harnad, S. R. (1972). Creativity, lateral saccades and the nondominant hemisphere. *Perceptual and Motor Skills, 34*, 653–654.

Hellige, J. B. (1993). *Hemispheric asymmetry*. Cambridge, MA: Harvard University Press.

Hellige, J. B. (1995). Coordinating the different processing biases of the left and right cerebral hemispheres. In F. Kitterle (Ed.), *Hemispheric communication: Mechanisms and models* (pp. 347–362). Hillsdale, NJ, England: Lawrence Erlbaum.

Hoppe, K. D. (1977). Split brains and psychoanalysis. *The Psychoanalytic Quarterly, 46*, 220–244.

Hoppe, K. D. (1978). Split-brain: Psychoanalytic findings and hypotheses. *Journal of the American Academy of Psychoanalysis, 6*, 193–213.

Hoppe, K. D. (1988). Hemispheric specialization and creativity. *Psychiatric Clinics of North America, 11*, 303–315.

Hoppe, K. D. (1989). Psychoanalysis, hemispheric specialization, and creativity. *Journal of the American Academy of Psychoanalysis, 17*, 253–269.

Hoppe, K. D., & Bogen, J. E. (1977). Alexithymia in twelve commissurotomized patients. *Psychotherapy and Psychosomatics, 28*, 148–155.

Hoppe, K., & Kyle, N. (1990). Dual brain, creativity, and health. *Creativity Research Journal, 3*, 150–157.

Ince, E., & Christman, S. (2002). Semantic representations of word meanings by the cerebral hemispheres. *Brain and Language, 80*, 3, 393–420.

Jasper, J. G., Barry, K., & Christman, S. D. (2008). Individual differences in counterfactual production. *Personality and Individual Differences, 45*, 488–492.

Jaušovec, N., & Jaušovec, K. (2000). Differences in resting EEG related to ability. *Brain Topography, 12*, 229–240.

Jung-Beeman, M. J., Bowden, E. M., Haberman, J., Frymiare, J. L., Arambel-Liu, S., Greenblatt, R. E., et al. (2004). Neural activity when people solve verbal problems with insight. *PLoS Biology, 2*(4), 500–510.

Keppel, G., & Wickens, T. D. (2004). *Design and analysis: A researcher's handbook*. Upper Saddle River, NJ: Prentice Hall.

Kessinger, E., & Choi, E. S. (2009). When side matters: Hemispheric processing and the visual specificity of emotional memories. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35*, 247–253.

Knauff, M., Mulack, T., Kassubek, J., Salih, H. R., & Greenlee, M. W. (2002). Spatial imagery in deductive reasoning: A Functional MRI Study. *Cognitive Brain Research, 13*, 203–212.

Koivisto, M. (1997). Time course of semantic activation in the cerebral hemispheres. *Neuropsychologia, 35*, 497–504.

Kounios, J., Frymiare, J. L., Bowden, E. M., Fleck, J. I., Subramaniam, K., Parrish, T. B., et al. (2006). The prepared mind: Neural activity prior to problem presentation predicts subsequent solution by sudden insight. *Psychological Science, 17*, 882–890.

Kwiatkowski, J. (2002). Individual differences in the neurophysiology of creativity. *Dissertation Abstracts International: Section B: The Sciences and Engineering, 63*, 3050.

Leonhard, M. A., & Brugger, P. (1998). Creative, paranormal, and delusional thought: A consequence of right hemisphere semantic activation? *Neuropsychiatry, Neuropsychology, and Behavioural Neurology, 11*, 177–183.

Lezak, M. D. (1995). *Thurstone word fluency test. Neuropsychological assessment*. New York: Oxford University Press. pp. 548–549.

Lohr, J. B., Hellige, J. B., Cherry, B., Lulow, L., Kwok, W., & Caligiuri, M. P. (2006). Impaired hemispheric communication in schizophrenia: A study using the consonant–vowel–consonant task. *Schizophrenia Research, 87*, 279–288.

Lyle, K. B., Logan, J. M., & Roediger, H. L. (2008). Eye movements enhance memory for individuals who are strongly right-handed and harm it for individuals who are not. *Psychonomic Bulletin & Review, 15*, 515–520.

Lyle, K. B., McCabe, D. P., & Roediger, H. L. (2008). Handedness is related to memory via hemispheric interaction: Evidence from paired associate recall and source memory tasks. *Neuropsychology, 22*, 523–530.

Martindale, C. (1999). Biological bases of creativity. In R. Sternberg (Ed.), *Handbook of creativity* (pp. 141). Cambridge University Press, 2004.

Martindale, C., Hines, D., Mitchell, L., & Covello, E. (1984). EEG alpha asymmetry and creativity. *Personality and Individual Differences, 5*, 77–86.

McCallum, R. S., & Glynn, Shawn M. (1979). Hemispheric specialization and creative behavior. *Journal of Creative Behavior, 13*, 263–273.

Mckeever, W. F., Seitz, K. S., Krutsch, A. J., & Van Eys, P. L. (1995). On language laterality in normal dextrals and sinistrals: Results from the bilateral object naming latency task. *Neuropsychologia, 33*, 1627–1635.

Miran, M., & Miran, E. (1984). Cerebral asymmetries: Neuropsychological measurement and theoretical issues. *Biological Psychology, 19*, 295–304.

Nettle, D. (2006). Schizotypy and mental health amongst poets, visual artists, and mathematicians. *Journal of Research in Personality, 40*, 876–890.

Niebauer, C. L., Aselage, J., & Schutte, C. (2002). Hemispheric interaction and consciousness: Degree of handedness predicts the intensity of a sensory illusion. *Laterality: Asymmetries of Body, Brain and Cognition, 7*, 85–96.

Niebauer, C., & Garvey, K. (2004). Godel, Escher, and degree of handedness: Differences in interhemispheric interaction predict differences in understanding self-reference. *Laterality, 9*, 19–34.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia, 9*, 97–113.

Pardo, J. V., Pardo, P. J., Janer, K. W., & Raichle, M. E. (1990). Anterior cingulate cortex mediates processing selection in the Stroop attentional conflict paradigm. *Proceedings of the National Academy of Sciences, 87*, 256–259.

Platel, H., Baron, J. C., Desgranges, B., Bernard, F., & Eustache, F. (2003). Semantic and episodic memory of music are subserved by distinct neural networks. *NeuroImage, 20*, 244–256.

Poreh, A. M., Whitman, D. R., & Ross, T. P. (1994). Creative thinking abilities and hemispheric asymmetry in schizotypal college students. *Current Psychology, 12*, 344–352.

Preti, A., & Vellante, M. (2007). Creativity and psychopathology: Higher rates of psychosis proneness and nonright-handedness among creative artists compared to same age and gender peers. *Journal of Nervous and Mental Disease, 195*, 837–845.

Propper, R. E., & Christman, S. D. (2004). Mixed- versus strong-handedness is associated with biases toward "Remember" versus "Know" judgments in recognition memory: Role of interhemispheric interaction. *Memory, 12*, 707–714.

Propper, R. E., & Christman, S. D. (2008). Interhemispheric interaction and saccadic horizontal eye movements: Implications for episodic memory, EMDR, and PTSD. *Journal of EMDR Practice & Research, 2*, 269–281.

Propper, R. E., Christman, S. D., & Phaneuf, K. A. (2005). A mixed-handed advantage in episodic memory: A possible role of interhemispheric interaction. *Memory & Cognition, 33*, 751–757.

Propper, R. E., Pierce, J., Geisler, M. W., Christman, S. D., & Bellorado, N. (2007). Effect of bilateral eye movements on frontal interhemispheric gamma EEG coherence: Implications for EMDR therapy. *Journal of Nervous & Mental Disease, 195*, 785–788.

Ramachandran, V. S. (1995). Anosognosia in parietal lobe syndrome. *Consciousness and Cognition, 4*, 22–51.

Rasmussen, T., & Milner, B. (1977). The role of early left-brain injury in determining lateralization of cerebral speech functions. *Annals of the New York Academy of Sciences, 299*, 355–369.

Razumnikova, O. M. (2007). Creativity related cortex activity in the remote associates task. *Brain Research Bulletin, 73*, 96–102.

Razumnikova, O. M., & Bryzgalov, A. O. (2006). Frequency–spatial organization of brain electrical activity in creative verbal thought: The role of the gender factor. *Neuroscience and Behavioral Physiology, 36*, 645–653.

Rosano, C., Krisky, C., Welling, J., Eddy, W., Luna, B., Thulborn, K., et al. (2002). Pursuit and saccadic eye movement subregions in human frontal eye field: A high resolution fMRI investigation. *Cerebral Cortex, 12*, 107–115.

Runco, M. A. (1985). Reliability and comergent validity or ideational flexibility as a function of academic achievement. *Perceptual and Motor Skills, 61*, 1075–1081.

Runco, M. (2004). Creativity. *Annual Review of Psychology, 55*, 657–687.

Runco, M. (2006). *Creativity: Theories and themes: Research, development and practice*. Academic Press.

Runco, M. A. (2008). Commentary: Divergent thinking is not synonymous with creativity. *Psychology of Aesthetics, Creativity, and the Arts, 2*, 93–96.

Runco, M. A., Illies, J. J., & Eisenman, R. (2005). Creativity, originality, and appropriateness: What do explicit instructions tell us about their relationships? *Journal of Creative Behavior, 39*, 137–148.

Runco, M. A., & Okuda, S. M. (1991). The instructional enhancement of the flexibility and originality scores of divergent thinking tests. *Applied Cognitive Psychology, 5*, 435–441.

Shemyakina, N. V., & Dan'ko, S. G. (2004). Influence of the emotional perception of a signal on the electroencephalographic correlates of creative activity. *Human Physiology, 30*, 145–151.

Siebörger, F. T., Ferstl, E. C., & von Cramon, D. Y. (2007). Making sense of nonsense: An fMRI study of task induced inference processes during discourse comprehension. *Brain Research, 1166*, 77–91.

Simonton, D. K. (2004). *Creativity in science: Chance, logic, genius, and zeitgeist*. New York: Cambridge University Press.

Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms fro name agreement, image agreement, familiarity, and visual complexity. *Journal of Bilateral EM Psychology: Human Learning and Memory, 6*, 174–215.

Sohn, M. H., Ursu, S., Anderson, J. R., Stenger, V. R., & Carter, C. (2000). The role of prefrontal cortex and posterior parietal cortex in task switching. *Proceedings of the National Academy of Sciences, 97*, 13448–13453.

Starchenko, M. G., Bekhtereva, N. P., Pakhomov, S. V., & Medvedev, S. V. (2003). Study of the brain organization of creative thinking. *Human Physiology, 29*, 652–653 [Translated from *Fiziologiya Cheloveka*, 29, 151–152].

Sternberg, R. J. (1998). *Handbook of creativity*. Cambridge University Press.

Sviderskaia, N. E., Antonov, A. G., & Butneva, L. S. (2007). Comparative analysis of spatial EEG organization on models of non-verbal divergent and convergent thinking. *Zh Vyssh Nerv Deiat Im I P Pavlova, 57*, 144–154.

Sviderskaya, N. E., Taratynova, G. V., & Kozhedub, R. G. (2006). The effects of the experience of forming visual images on the spatial organization of the EEG. *Neuroscience and Behavioral Physiology, 36*, 941.

Torrance, E. P., & Horng, R. Y. (1980). Creativity and style of learning and thinking characteristics of adaptors and innovators. *Creative Child & Adult Quarterly, 5*, 80–85.

Tulving, E., Kapur, S., Craik, F., Moscovitch, M., & Houle, S. (1994). Hemispheric encoding/retrieval asymmetry in episodic memory: Positron emissions tomography findings. *Proceedings of the National Academy of Sciences, 91*, 2016–2020.

Weinstein, S., & Graves, R. (2002). Are creativity and schizotypy products of a right hemisphere bias? *Brain and Cognition, 49*, 138–151.

Weisberg, R. W., & Alba, J. W. (1981). An examination of the alleged role of 'fixation' in the solution of several 'insight' problems. *Journal of Experimental Psychology: General, 110*, 169–192.

Welcome, S. E., Chiarello, C., Towler, S., Halderman, L. K., Otto, R., & Leonard, C. M. (2009). Behavioral correlates of corpus callosum size: Anatomical/behavioral relationships vary across sex/handedness groups. *Neuropsychologia, 47*, 2427–2435.

Witelson, S. F., & Goldsmith, C. H. (1991). The relationship of hand preference to anatomy of the corpus callosum in men. *Brain Research, 545*, 175–182.