CREATIVITY RESEARCH JOURNAL, *29*(1), 78–85, 2017

ISSN: 1040-0419 print/1532-6934 online
DOI: 10.1080/10400419.2017.1263502

RESEARCH NOTE

Intelligence Level and the Allocation of Resources for Creative Tasks: A Pupillometry Study

Amitash Ojha
Kyungpook National University, Korea

Bipin Indurkhya
Institute of Philosophy, Jagiellonian University, Poland

Minho Lee
School of Electronics Engineering, Kyungpook National University, Taegu, Korea

This pupillometry study examined the relationship between intelligence and creative cognition from the resource allocation perspective. It was hypothesized that, during a creative metaphor task, individuals with higher intelligence scores would have different resource allocation patterns than individuals with lower intelligence scores. The study also examined the influence of intelligence in language and visuo-spatial domains on the resource allocation mechanism of verbal and visual creativity. The results suggested that individuals with higher intelligence scores allocated more cognitive resources for creative tasks than those with lower intelligence scores but not for non-creative tasks. The findings of this study support the view that creativity requires allocation of several cognitive faculties and may share underlying cognitive and neural mechanisms with intelligence. Domain-specific intelligence did not seem to play a significant role in the same domain, as individuals with higher scores in both domains showed similar resource allocation patterns. However, individuals with higher intelligence scores in the visuo-spatial domain generated more creative metaphorical interpretations in both verbal and visual creative metaphor tasks suggesting its importance in creative cognition.

The relationship between intelligence and creative cognition has been widely debated and still remains a controversial issue in the psychology of creativity (Kaufman & Beghetto, 2009). Most scholars maintain that creativity and intelligence are distinct abilities with small overlap (Kaufman & Plucker, 2011; Runco, 2007). Some research has suggested that creative cognition, usually measured with divergent thinking tasks, covaries modestly with intelligence (Kim, 2005; Silvia, 2008). However, many contemporary researchers have also argued that there are good reasons to expect stronger relationships between intelligence and creative cognition as both engage similar cognitive functions (Silvia, 2015). Generating creative ideas that are both novel and appropriate requires identifying and implementing strategies for idea generation as well as exerting control over attention and thought (Vartanian, 2009)—making decisions to refine initial ideas (Cheng, Hu, Jia, & Runco, 2015; Vartanian,

We are thankful to Ms. Harini Sampath (International Insitute of Information Technology, Hyderabad, India) and JunSu Kang (Kyungpook National University, Daegu, South Korea) for their help in conducting experiments and analyzing data.

This work was partly supported by the ICT R&D program of MSIP/IITP [R7124-16-0004, Development of Intelligent Interaction Technology Based on Context Awareness and Human Intention Understanding] (50%) and by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. NRF-2016R1A2A2A05921679) (50%).

Address correspondence to Amitash Ojha, Department of Pedagogy, Psychology, Philosophy, University of Cagliari, Cagliari, Italy. Email: amitashojha@gmail.com .

Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/HCRJ.

2009), and weeding out obvious and irrelevant ideas (Smith, Ward, & Schumacher, 1993).

In this regard, an alternative and novel way to study the relationship between intelligence and creativity is to determine the difference in cognitive resource allocation patterns of individuals with varying intelligence scores when they perform creative tasks. Here, resources are defined as the amount of activation available for information storage and processing in the underlying cortical neural system. This pool of resources is assumed to be limited and dependent on (a) neurotransmitter functioning, (b) metabolic system supporting the neural system, and (c) the structural connectivity of the neural system (Just, Carpenter, & Miyake, 2003).

Though there are only a few resource-allocation studies on creativity (Fink & Benedek, 2014), such studies have played a major role in illuminating the mechanism of intelligence and differentiating between the cognitive processes of individuals with higher and lower intelligence (Lee, Ojha, Kang, & Lee, 2015; Neubauer & Fink, 2009; Van Der Meer et al., 2010). It has been argued that variation within the availability of resources and their allocation mechanism are the primary basis for the individual differences in intelligence. Several hypotheses have been proposed in this regard to explain the resource allocation patterns of individuals with higher intelligence, as compared to those with lower intelligence. For instance, the neural efficiency hypothesis suggests that individuals with higher intelligence allocate fewer resources but use them efficiently (Ahern & Beatty, 1979). In contrast, resource hypothesis proposes that individuals with higher intelligence have extra resources to allocate for a task (Van Der Meer et al., 2010).

Creative cognition, similar to intelligence, also requires allocation of cognitive resources. Although the prevalent view suggests that creative insights are intuitive and spontaneous (Shirley & Langan-Fox, 1996), several researchers have argued that creativity requires a deliberate and methodological problem-solving strategy (e.g., Gardner, 1988; Guilford, 1982; Sternberg, 2006), which includes various executive functions such as working memory, perception, attention, etc. (Weisberg, 1993). This view is further supported by the brain imaging studies (Katz, 1997), and the cognitive framework proposed by Dietrich (2004) on the neural basis of creativity, which suggests a common underlying neural mechanism for both intelligence and creativity. Therefore, considering that (a) both intelligence and creativity requires consumption of resources and (b) intelligent individuals have different ways of allocating them for a task, it is possible to hypothesize that intelligent individuals may also have different resource allocation strategies for creative and non-creative tasks. The similarity or differences in resource allocation patterns can further illuminate the relationship between intelligence and creative cognition. Consequently, the first goal of this study was to explore the resource allocation patterns of individuals with higher and lower intelligence scores when they performed creative and non-creative tasks.

The second goal of this study was to understand the domain-specific creativity and its relation with the resource-allocation patterns of individuals with varying intelligence scores in the same domain. Generally, it has been argued that higher-level cognitive processes are not domain specific, i.e., a creative person in one domain (e.g., verbal) tends to be creative in another domain (e.g., visual). For example, according to Simonton's hierarchical model, creativity varies on a single dimension (Simonton, 2009). In contrast, some researchers have argued that creativity depends mainly on domain-specific skills (Silvia, Kaufman, & Pretz, 2009). According to this view, visuo-spatial abilities appear to be most important for visual creativity. It must be noted here that domain-specific intelligence is a well-researched issue in educational psychology (Petsche, 1996; Vitouch, Bauer, Gittler, Leodolter, & Leodolter, 1997): studies have shown that individuals allocate resources differently in different domains according to the task type and complexity (Lee et al., 2015). So considering this, it is possible that domain-specific skills and intelligence play a significant role in the resource-allocation pattern in the creative tasks of the same domain.

However, to analyze this relationship from a resource-allocation perspective, three methodological issues need to be considered. First is to decide on a measure of intelligence, as it is highly controversial. Researchers have argued that measuring intelligence with a single score is not enough or justified (Neisser et al., 1996), and individuals have different intelligence potentials in different domains. In this study, intelligence was measured in two domains, namely *language* and *visuo-spatial*. The second issue is associated with the assessment of resource allocation. In this regard, different measures of activity as indices of resource allocation have been verified (Just et al., 2003). Among these, the most common is the assessment of pupil dilation. Research has shown that the pupil dilates more when the processing demand is higher. Pupil dilation also indicates sustained information processing, preparation (Granholm, Asarnow, Sarkin, & Dykes, 1996), complex-stimuli interpretation (Beatty, 1982), deception (Wang, Spezio, & Camerer, 2010), and affective processing partially connected with creativity (Partala & Surakka, 2004). Hence, in this study, pupil dilation was taken to be a measure of resource allocation. Finally, the last issue is related to creative tasks. For this study, creative verbal and visual metaphor tasks were chosen, as they constitute good examples of real-world creativity (Lubart & Getz, 1997; Sanchez-Ruiz, Santos, & Jiménez, 2013; Seitz, 1997). Moreover, metaphors provide instances of creativity not only in speech and written text, but also in images and other modalities (Forceville, 2006; Indurkhya & Ojha, 2013; Kennedy, 1982).

METHOD

Participants

Forty-five high school students (21 girls and 24 men), with a mean age of 21 years (*SD* = 1.7) from universities around Seoul, South Korea, participated in the study. Their participation was voluntary. All participants were right-handed as assessed by the Edinburgh handedness inventory (Oldfield, 1971), and had normal or corrected-to-normal vision. They had no reported history of neurological or psychiatric diseases. All the participants were fluent in English (based on their TOEIC scores). It was also confirmed that participants were not taking any medications.

Pretest

Before the actual experiment, all the participants went through a pretest to determine their level of intelligence in *language* and *visuo-spatial* domains. For this, the standard Korean intelligence test (developed by Korea Employment Information Service in 2003) was chosen, which measures several aspects of intelligence through questions related to different domains of intelligence such as language, mathematics, visuo-spatial, etc. The test included 238 questions and participants were given a positive score for each correct answer.

Stimulus Material

Two sets of stimuli, verbal and visual, were prepared for this study.

Verbal stimuli

A total of 36 sentences (12 metaphors, 12 literals, and 12 anomalous) from the work of Shibata, Abe, Terao, and Miyamoto (2007) were chosen as the verbal stimuli. The sentences were in simple "X is Y" format (e.g., Literal: "A dolphin is an animal;" "A crow is a bird." Metaphor: "Education is stairs;" "Smile is a flower." Anomalous: "Milk is pajamas;" "The star is a curry.").

Visual stimuli

Visual stimuli were created in two steps. In the first step, two sets of images (200) were taken from Internet. The first set included 100 normal and congruous scenes depicting nature, cities, classrooms, etc. and the second set included 100 incongruous images that could be interpreted metaphorically. The luminance and contrast levels of the images were digitally equated using the Adobe Photoshop software. Then these 200 images were shown to 13 participants, who were asked to rate them on the following two dimensions: (a) understandability and (b) figurativeness. Each image was presented on the screen and the participants were asked to press the spacebar when they decided on its understandability and figurativeness. This brought them to the next screen, where they were asked to rate the image. First they were asked to rate the understandability of the image on a scale of 0–5 (0 = *least meaningful*; 5 = *very meaningful*). Then they were asked to rate the figurativeness of the image on a scale of 0–5 (0 = *literal*; 5 = *highly metaphorical*). Both sets of images were presented randomly on an online portal.

In the second step, the ratings of all the participants were averaged for each of the two dimensions. Twelve images that were rated high on meaningfulness (average: 4.1) and high on figurativeness (average: 4.6) were chosen as metaphor images. Twelve images that were rated high on meaningfulness (average: 4.8) and low on figurativeness (average: 0.7) were chosen as literal images. Also, 12 images that were rated low on both meaningfulness (average: 0.6) and figurativeness (average: 0.3) were chosen as anomalous images (see Figure 1). This study used complex images to tap more heavily into semantic system (Jouen et al., 2015). Apart from this, 12 control visual stimuli were also prepared for the visual condition.

Pupil Baseline Task

This was a calibration procedure prior to any task instructions to obtain the baseline pupil size of the participants. The baseline data were also used to remove the effect of stimulus-related intensity (luminance), gaze angle, and adaptation time-response of pupillary light reflex to variation in intensity (Jang, Mallipeddi, Lee, Kwak, & Lee, 2014). Participants were asked to fixate on a plus (+) sign, presented five times for 10 sec. The duration between the fixations was 10 sec. The individual average pupil diameter during the 10 sec of fixation was taken as the pupil baseline, not influenced by any instructional and expectation effects. The baseline task was conducted before the presentation of each block.

Procedure and Data Acquisition

Participants were called and seated in a comfortable chair in a dimly lit (luminance 180 ± 20 lux) and sound-attenuated

FIGURE 1 Examples of visual stimuli (a) control image, (b) literal image, (c) metaphorical image, (d) anomalous image.

chamber. An eye-tracker (Tobii 1750) was used to record the pupil variation and the response time while the participants performed creative metaphor interpretation task. Stimuli were presented on a 21-inch screen monitor (1280 × 1024). The distance between the participants and the screen was around 60–80 cms. At the beginning of the experiment, participants filled out a questionnaire that ascertained demographic data, as well as factors known to affect pupil dilation (e.g., psychiatric and neurological dysfunction, drug consumption, medication). Then they were calibrated on the Tobii eye tracker and their baseline data were collected before the presentation of each block. For the actual experiment, in the verbal run, 12 sentences (four literals, four metaphorical, and four anomalous) were presented in three blocks. For the visual run, 16 images (four literal images, four metaphorical images, four anomalous images, and four control images) were presented in three blocks. There was a gap of 10 sec between consecutive stimuli. The stimuli in each block were presented randomly, but were the same for all participants. Order of the block was decided beforehand. Stimuli were presented in blocks to reduce the participants' fatigue and order effect.

Participants were instructed to decide if the given sentence or image was literal, metaphorical, or anomalous (noncomprehensible). They were explicitly instructed to "be creative" (e.g., Niu & Liu, 2009). They were also instructed to press the space bar to go to the next stimulus if they did not want to answer, the stimulus changed after 10 sec and a new stimulus appeared. The overall experiment took around 20~25 min, though there were some variations among individual participants (±10 min). Once the participants finished the experiment, they were shown again the stimuli they categorized as metaphorical, and were asked to interpret each stimulus. Their oral responses were recorded and later transcribed for analyzing the level of creativity in interpretations.

Task

Interpreting creative metaphors was considered to be the creative task in this experiment. Different metaphors tasks have been proposed in the literature such as simile insertion, simile completion, metaphor completion, etc. (De Barros, Primi, Miguel, Almeida, & Oliveira, 2010). However, one method, used mostly in neuroscience research, is metaphor interpretation task. In this task, a sentence is given, and the participants are asked to decide if it is literal, metaphorical, or anomalous (Indurkhya & Ojha, 2013; Shibata et al., 2007). If the participant decides that the sentence is metaphorical, then she or he is asked to provide an interpretation for it. In this study, the metaphor interpretation task was used for two reasons. First, it was assumed that it distinguishes between the processes involved in literal, metaphorical and anomaly interpretation. Second, this study used visual modalities, and if the study used, for example, metaphor completion task for visual images, then the quality of answer would depend on the drawing ability of the participant.

Creative Task Scoring

Irrespective of the stimulus precategorization, the participants' responses were categorized into *metaphorical, literal*, and *anomalous*. Five raters (graduate students conducting research on psychology of creativity) judged each metaphor independently: they were not given any information about the scoring of the other raters or about the participants and their response to other metaphors. Each metaphor was assigned a random number, and then all metaphors were sorted in the numerical order. The raters scored each metaphor on a 5-point scale (1 = *not at all creative*; 5 = *very creative*). Scorers were given the pointers such as: Is the interpretation interesting, funny, striking, etc.? A final score of creativity was assigned to each interpretation based on the inter-rater agreement (KAPPA 0.78, $p < .01$).

Data Organization and Analysis

Behavioral data (response times) was analyzed using the Statistical Package for the Social Sciences (SPSS). Pupillary response was analyzed using Matlab 7.1 and statistical software (SPSS). Artifacts due to excessive blinking were removed. Very small blinks (less than 3 sec) were replaced by linear interpolation. Pupil size can also be effected by external factors like the luminance of stimulus, gaze angles, etc. To remove these effects, the data were processed using the methods of Jang et al. (2014) and Lee et al. (2015). To represent the change in pupil size, adjustments were made for the fact that the pupil size varies for individuals. To compensate for individual variations, pupil size in the baseline task was used as the standard. The experimental pupil data were calculated, and change in the pupil size was represented as a percentage of the baseline pupil size (Lee et al., 2015).

RESULTS

Behavioral Results

The response time was calculated for the participants in both the verbal and the visual tasks. In the verbal condition, the participants took longer to interpret the metaphorical (6.09 sec) and the anomalous sentences (6.10 sec) than the literal sentences (4.41 sec). A one-way ANOVA revealed that the difference was significant $F(2,88) = 5.67$, $p < .01$. Similarly, in the visual condition, the participants took longer to interpret the metaphorical (5.48 sec) and the anomalous images (7.34 sec) than the literal images (3.45 sec). A one-way ANOVA revealed that the difference was significant $F(2,88) = 3.59$, $p < .05$ (Figure 2).

Pupil Response

The pupil-size variation in literal, metaphor, and anomaly conditions was analyzed as a percentage of the baseline

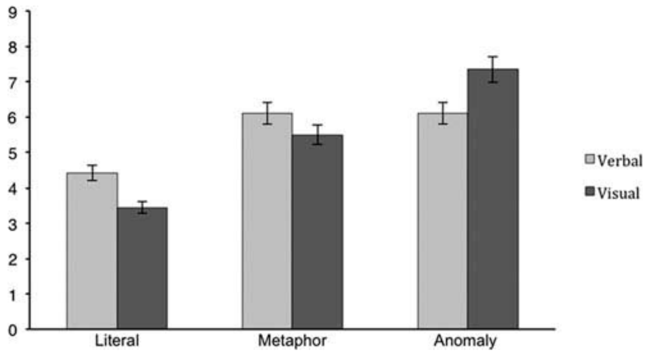

FIGURE 2 Response times in metaphor, literal and anomaly conditions for visual and verbal tasks.

pupil size, after removing the noise based on the methods applied by Jang et al. (2014) and Lee et al. (2015). Separate linear regression models were created for verbal and visual conditions. In the linear regression, continuous scores (0–248) in both the language and visuo-spatial domains were taken to be the independent variable. The change in the pupil-size diameter (as a percentage of the baseline pupil size) was considered to be the dependent variable to measure the allocation of cognitive resources.

Verbal condition

For the verbal condition, both language and visuo-spatial scores were found to be significant predictors of the pupil size during metaphorical and anomalous interpretations. Language score was not found to be a significant predictor of the pupil size in the literal task. Overall, as the intelligence scores in language and visuo-spatial domains increased, the pupil size also increased in the creative metaphor interpretation task but not in the literal interpretation task (Table 1).

Visual condition

Similar results were found in the visual condition. Intelligence scores of language and visuo-spatial intelligence scores were significant predictors of the pupil size during the metaphorical and anomalous interpretations but not during the literal interpretation. In general, the pupil size increased during the metaphorical and anomalous interpretations as the intelligence scores increased (Table 2).

The correlation between the creativity and intelligence scores in both the verbal and visual domain was assessed using the Pearson's r measure (Table 3). It was found that the creativity scores were positively correlated with the intelligence scores of visuo-spatial domain in the verbal condition, and with both the scores in the visual condition.

TABLE 1
Standard Multiple Regressions of intelligence scores in language and visuo-spatial on change in pupil size in various conditions

Condition	*Predictors*	β	t	N	df	F	R^2
Literal				43	2	3.74*	.14
	Language	−0.01	−1.62				
	Visuo-spatial	.02	1.62				
Metaphor				43	2	37.30*	.63
	Language	.03	2.95*				
	Visuo-spatial	.07	3.51**				
Anomaly				43	2	56.92**	.72
	Language	.15	4.43***				
	Visuo-spatial	.08	2.31*				

**p < .05, ** p < .01, *** p < .001*

TABLE 2
Standard Multiple Regressions of intelligence scores in language and visuo-spatial on change in pupil size in various conditions

Conditions	*Predictors*	β	t	N	df	F	R^2
Literal				43	2	1.21	.05
	Language	−0.02	−1.43				
	Visuo-spatial	.02	1.50				
Metaphor				43	2	72.36***	.77
	Language	.14	4.38***				
	Visuo-spatial	.11	3.26**				
Anomaly				43	2	69.61***	.76
	Language	.09	4.17***				
	Visuo-spatial	.07	3.23**				

DISCUSSION

Individuals with higher intelligence scores showed a significant increase in the size of pupil diameter during creative verbal and visual metaphor interpretations, but not during the literal interpretations. As discussed earlier, an increase in the pupil size during stimulus processing indicates sustained information-processing load (Hyona, Tommola and Alaja, 1995) as well as allocation of resources (Beatty, 1982; Van Der Meer et al., 2010). Increased pupil size also indicates preparation (Lee et al., 2015; Sirevaag et al., 1999) and attention (Hoeks & Levelt, 1993). Confirming the first hypothesis, the results showed that the resource allocation mechanism is different for individuals with different intelligence scores while performing the creative and noncreative tasks. Individuals with higher intelligence scores seem to allocate more cognitive resources to process information needed for creative tasks and fewer resources for noncreative tasks. They also appear to allocate more preparatory and attention resources for creative tasks than individuals with lower intelligence scores. This result also supports the view that creative insights result from preparation, deliberation and focused attention, all of which requires allocation of various cognitive resources. It must be noted that these features of information processing also characterize information processing during intelligence tasks. A similar pattern for the individuals with high intelligence scores in intelligence tasks

TABLE 3.
Creativity score vs intelligence score correlation

	Verbal		*Visual*	
	Language score	*Visuo-spatial score*	*Language score*	*Visuo-spatial score*
Creativity score	0.33 (p = 0.011)	0.63 (p = 0.003)	0.22 (p = 0.131)	0.69 (p = 0.001)

and creative tasks suggests that the underlying neural mechanism may be the same, and creative cognition and intelligence may be closely associated.

It was also hypothesized that the domain-specific intelligence plays a significant role in the resource allocation patterns during creative tasks in the same domain. In other words, individuals with high intelligence scores in language were hypothesized to perform better in the creative verbal-metaphor task and individuals with high intelligence scores in the visuo-spatial domain were hypothesized to perform better in the creative visual-metaphor task. The results suggest that individuals with high intelligence scores in the visuo-spatial domain generated more creative interpretations for both verbal and visual metaphors. However, it was also found that individuals with higher intelligence scores in both domains showed similar changes in the size of pupil diameter. This suggests that both groups allocated similar cognitive resources for creative tasks. So there was no difference between highly intelligent individuals in the language and visuo-spatial domains from the resource allocation perspective. But individuals with higher intelligence scores in the visuo-spatial domain performed better in terms of creative interpretation.

Individuals with higher intelligence scores in the visuo-spatial domain generated highly creative interpretations in verbal condition but not in the visual condition. This finding is consistent with the notion that visual creativity is largely domain and task specific, whereas verbal creativity, even though mostly domain specific, may, to some extent, be sensitive to processes in the visual domain as well (Palmiero et al., 2011). One possible explanation in relation to metaphorical creativity is that verbal metaphors were not presented in any context. Participants were allowed to imagine any context and situation to render them meaningful. Some studies have shown that readers generate better and more creative interpretations if they have good imagination or if they are allowed to imagine a context themselves (Indurkhya, 2007, 2016; Kövecses, 2009). Visual metaphors were also presented without any context, but visual features of these metaphors could have provided the context implicitly, thereby restricting the participants from making distant conceptual associations (Forceville & Urios-Aparisi, 2009; Mitchell, 1995; Ojha & Indurkhya, 2016). Moreover, notions of highly creative and less creative interpretations are somewhat subjective: They are qualitative in nature, and there is no universally agreed criterion to determine the quality of creativity (Cropley, 2000). This is particularly so for metaphors, where an association needs to be created between the source and the target: Any posited connection between the source and target, however novel, is not necessarily considered to be creative by different people. It must also be noted that intelligence in the visuo-spatial domain has been shown to be associated with creative reasoning and imagery (Silvia & Beaty, 2012; Sligh, Conners, & Roskos-Ewoldsen, 2005).

A significant increase in the pupil size was also observed during the interpretation of verbal and visual anomalous stimuli for individuals with higher intelligence scores in both domains. This suggests that interpreting an anomalous stimulus requires additional resources similar to interpreting a metaphor. This finding provides support for the creative metaphor comprehension process suggested by the pragmatic model of metaphor processing. In the standard pragmatic model (Gibbs & Gerrig, 1989; Glucksberg, 1991), it is claimed that metaphorical interpretation is a two-step process: first an attempt to understand the stimuli literally, and then to interpret it metaphorically. The model suggests that after failing to arrive at a literal interpretation, additional effort is made to find another interpretation for the seemingly anomalous stimulus. If the effort is successful, a figurative meaning is attempted and if the process fails again, the stimulus is rendered anomalous. Increased pupil dilation for both verbal and visual anomalous stimuli may indicate an attempt to find alternative interpretations and allocation of extra resources in the process.

REFERENCES

Ahern, S., & Beatty, J. (1979). Pupillary responses during information processing vary with Scholastic Aptitude Test scores. *Science*, *205* (4412), 1289–1292. doi:10.1126/science.472746

Beatty, J. (1982). Task-evoked pupillary responses, processing load, and the structure of processing resources. *Psychological Bulletin*, *91*(2), 276–292. doi:10.1037/0033-2909.91.2.276

Cheng, L., Hu, W., Jia, X., & Runco, M. A. (2015). The different role of cognitive inhibition in early versus late creative problem finding. *Psychology of Aesthetics, Creativity, and the Arts*, *10*(1), 32–41. doi:10.1037/aca0000036

Cropley, A. J. (2000). Defining and measuring creativity: Are creativity tests worth using? *Roeper Review*, *23*(2), 72–79. doi:10.1080/02783190009554069

De Barros, D. P., Primi, R., Miguel, F. K., Almeida, L. S., & Oliveira, E. P. (2010). Metaphor creation: A measure of creativity or intelligence. *European Journal of Education and Psychology*, *3*(1), 103–115.

Dietrich, A. (2004). The cognitive neuroscience of creativity. *Psychonomic Bulletin & Review*, *11*(6), 1011–1026. doi:10.3758/BF03196731

Fink, A., & Benedek, M. (2014). EEG alpha power and creative ideation. *Neuroscience & Biobehavioral Reviews*, *44*, 111–123. doi:10.1016/j.neubiorev.2012.12.002

Forceville, C. (2006). Non-verbal and multimodal metaphor in a cognitivist framework: Agendas for research. *Applications of Cognitive Linguistics*, *1*, 379.

Forceville, C., & Urios-Aparisi, E. (2009). *Multimodal metaphor* (Vol. 11). New York: Walter de Gruyter.

Gardner, H. (1988). Creativity: An interdisciplinary perspective. *Creativity Research Journal*, *1*(1), 8–26. doi:10.1080/10400418809534284

Gibbs, R. W., Jr, & Gerrig, R. J. (1989). How context makes metaphor comprehension seem 'special'. *Metaphor and Symbol*, *4*(3), 145–158. doi:10.1207/s15327868ms0403_3

Glucksberg, S. (1991). Beyond literal meanings: The psychology of allusion. *Psychological Science*, *2*(3), 146–152. doi:10.1111/psci.1991.2.issue-3

Granholm, E., Asarnow, R. F., Sarkin, A. J., & Dykes, K. L. (1996). Pupillary responses index cognitive resource limitations. *Psychophysiology*, *33*(4), 457–461. doi:10.1111/psyp.1996.33.issue-4

Guilford, J. P. (1982). Is some creative thinking irrational? *The Journal of Creative Behavior*, *16*(3), 151–154. doi:10.1002/jocb.1982.16.issue-3

Hoeks, B., & Levelt, W. J. (1993). Pupillary dilation as a measure of attention: A quantitative system analysis. *Behavior Research Methods, Instruments, & Computers*, *25*, 16–26. doi:10.3758/BF03204445

Hyönä, J., Tommola, J., & Alaja, A. M. (1995). Pupil dilation as a measure of processing load in simultaneous interpretation and other language tasks. *The Quarterly Journal of Experimental Psychology*, *48*(3), 598–612. doi:10.1080/14640749508401407

Indurkhya, B. (2007). Creativity in interpreting poetic metaphors. In T. Kusumi (Ed.), *New directions in metaphor research* (pp. 483–501). Tokyo, Japan: Hitsuji Shobo.

Indurkhya, B. (2016). Towards a model of metaphorical understanding. In G. Elisabetta, & E. Francesca (Eds.), *Metaphor and communication*. Amsterdam, The Netherlands: John Benjamin.

Indurkhya, B., & Ojha, A. (2013). An empirical study on the role of perceptual similarity in visual metaphors and creativity. *Metaphor and Symbol*, *28*(4), 233–253. doi:10.1080/10926488.2013.826554

Jang, Y. M., Mallipeddi, R., Lee, S., Kwak, H. W., & Lee, M. (2014). Human intention recognition based on eyeball movement pattern and pupil size variation. *Neurocomputing*, *128*, 421–432. doi:10.1016/j.neucom.2013.08.008

Jouen, A. L., Ellmore, T. M., Madden, C. J., Pallier, C., Dominey, P. F., & Ventre-Dominey, J. (2015). Beyond the word and image: Characteristics of a common meaning system for language and vision revealed by functional and structural imaging. *NeuroImage*, *106*, 72–85. doi:10.1016/j.neuroimage.2014.11.024

Just, M. A., Carpenter, P. A., & Miyake, A. (2003). Neuroindices of cognitive workload: Neuroimaging, pupillometric and event-related potential studies of brain work. *Theoretical Issues in Ergonomics Science*, *4*(1–2), 56–88. doi:10.1080/14639220210159735

Katz, A. (1997). Creativity in the cerebral hemispheres. *Creativity Research Handbook*, *1*, 203–226.

Kaufman, J. C., & Beghetto, R. A. (2009). Beyond big and little: The four c model of creativity. *Review of General Psychology*, *13*(1), 1–12. doi:10.1037/a0013688

Kaufman, J. C., & Plucker, J. A. (2011). Intelligence and creativity. In R.J. Steinberg, S.B. Kaufman (Eds.), *The Cambridge handbook of intelligence* (2011), pp. 771–783).

Kennedy, J. M. (1982). Metaphor in pictures. *Perception*, *11*(5), 589–605. doi:10.1068/p110589

Kim, K. H. (2005). Can only intelligent people be creative? A meta-analysis. *Prufrock Journal*, *16*(2–3), 57–66.

Kövecses, Z. (2009). Metaphor and poetic creativity: A cognitive linguistic account. *Acta Universitatis Sapientiae Philologica*, *Philologica, 1*, 181–196.

Lee, G., Ojha, A., Kang, J. S., & Lee, M. (2015). Modulation of resource allocation by intelligent individuals in linguistic, mathematical and visuo-spatial tasks. *International Journal of Psychophysiology*, *97*(1), 14–22. doi:10.1016/j.ijpsycho.2015.04.013

Lubart, T. I., & Getz, I. (1997). Emotion, metaphor, and the creative process. *Creativity Research Journal*, *10*(4), 285–301. doi:10.1207/s15326934crj1004_1

Mitchell, W. T. (1995). *Picture theory: Essays on verbal and visual representation*. University of Chicago Press.

Neisser, U., Boodoo, G., Bouchard, T. J., Jr, Boykin, A. W., Brody, N., Ceci, S. J., … Urbina, S. (1996). Intelligence: Knowns and unknowns. *American Psychologist*, *51*(2), 77. doi:10.1037/0003-066X.51.2.77

Neubauer, A. C., & Fink, A. (2009). Intelligence and neural efficiency. *Neuroscience & Biobehavioral Reviews*, *33*(7), 1004–1023. doi:10.1016/j.neubiorev.2009.04.001

Niu, W., & Liu, D. (2009). Enhancing creativity: A comparison between effects of an indicative instruction "to be creative" and a more elaborate heuristic instruction on Chinese student creativity. *Psychology of Aesthetics, Creativity, and the Arts*, *3*(2), 93. doi:10.1037/a0013660

Ojha, A., & Indurkhya, B. (2016). On the role of perceptual features in metaphor comprehension. In G. Elisabetta, & E. Francesca (Eds.), *Metaphor and communication*. Amsterdam, The Netherlands: John Benjamin.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, *9*(1), 97–113. doi:10.1016/0028-3932(71)90067-4

Palmiero, M., Cardi, V., & Belardinelli, M. O. (2011). The role of vividness of visual mental imagery on different dimensions of creativity. *Creativity Research Journal*, *23*(4), 372–375.

Partala, T., & Surakka, V. (2004). The effects of affective interventions in human–computer interaction. *Interacting with Computers*, *16*(2), 295–309. doi:10.1016/j.intcom.2003.12.001

Petsche, H. (1996). Approaches to verbal, visual and musical creativity by EEG coherence analysis. *International Journal of Psychophysiology*, *24*(1), 145–159. doi:10.1016/S0167-8760(96)00050-5

Runco, M. A. (2007). Creativity: Theories and themes: Research. In *Development and practice*. Amsterdam, The Netherlands: Elsevier.

Sanchez-Ruiz, M. J., Santos, M. R., & Jiménez, J. J. (2013). The role of metaphorical thinking in the creativity of scientific discourse. *Creativity Research Journal*, *25*(4), 361–368. doi:10.1080/10400419.2013.843316

Seitz, J. A. (1997). The development of metaphoric understanding: Implications for a theory of creativity. *Creativity Research Journal*, *10*(4), 347–353. doi:10.1207/s15326934crj1004_6

Shibata, M., Abe, J. I., Terao, A., & Miyamoto, T. (2007). Neural mechanisms involved in the comprehension of metaphoric and literal sentences: An fMRI study. *Brain Research*, *1166*, 92–102. doi:10.1016/j.brainres.2007.06.040

Shirley, D. A., & Langan-Fox, J. (1996). Intuition: A review of the literature. *Psychological Reports*, *79*(2), 563–584. doi:10.2466/pr0.1996.79.2.563

Silvia, P. J. (2008). Creativity and intelligence revisited: A latent variable analysis of Wallach and Kogan (1965). *Creativity Research Journal*, *20*(1), 34–39. doi:10.1080/10400410701841807

Silvia, P. J. (2015). Intelligence and creativity are pretty similar after all. *Educational Psychology Review*, *27*, 599–606.

Silvia, P. J., & Beaty, R. E. (2012). Making creative metaphors: The importance of fluid intelligence for creative thought. *Intelligence*, *40*(4), 343–351. doi:10.1016/j.intell.2012.02.005

Silvia, P. J., Kaufman, J. C., & Pretz, J. E. (2009). Is creativity domain-specific? Latent class models of creative accomplishments and creative self-descriptions. *Psychology of Aesthetics, Creativity, and the Arts*, *3*(3), 139. doi:10.1037/a0014940

Simonton, D. K. (2009). Varieties of (scientific) creativity a hierarchical model of domain-specific disposition, development, and achievement. *Perspectives on Psychological Science*, *4*(5), 441–452. doi:10.1111/j.1745-6924.2009.01152.x

Sirevaag, E. J., Rohrbaugh, J. W., Stern, J. A., Vedeniapin, A. B., Packingham, K. D., & LaJonchere, C. M. (1999). *Multi-dimensional* *characterizations of operator state: A validation of oculomotor metrics*. St. Louis, MO: Washington University, Department of Psychology.

Sligh, A. C., Conners, F. A., & Roskos-Ewoldsen, B. E. V. E. R. L. Y. (2005). Relation of creativity to fluid and crystallized intelligence. *The Journal of Creative Behavior*, *39*(2), 123–136. doi:10.1002/jocb.2005.39.issue-2

Smith, S. M., Ward, T. B., & Schumacher, J. S. (1993). Constraining effects of examples in a creative generation task. *Memory & Cognition*, *21*(6), 837–845. doi:10.3758/BF03202751

Sternberg, R. J. (2006). The nature of creativity. *Creativity Research Journal*, *18*(1), 87–98. doi:10.1207/s15326934crj1801_10

Van Der Meer, E., Beyer, R., Horn, J., Foth, M., Bornemann, B., Ries, J., … Wartenburger, I. (2010). Resource allocation and fluid intelligence: Insights from pupillometry. *Psychophysiology*, *47*(1), 158–169. doi:10.1111/j.1469-8986.2009.00884.x

Vartanian, O. (2009). Variable attention facilitates creative problem solving. *Psychology of Aesthetics, Creativity, and the Arts*, *3*(1), 57. doi:10.1037/a0014781

Vitouch, O., Bauer, H., Gittler, G., Leodolter, M., & Leodolter, U. (1997). Cortical activity of good and poor spatial test performers during spatial and verbal processing studied with slow potential topography. *International Journal of Psychophysiology*, *27*(3), 183–199. doi:10.1016/S0167-8760(97)00060-3

Wang, J. T. Y., Spezio, M., & Camerer, C. F. (2010). Pinocchio's pupil: Using eyetracking and pupil dilation to understand truth telling and deception in sender--receiver games. *American Economic Review*, *100*, 3. doi:10.1257/aer.100.3.984

Weisberg, R. W. (1993). *Creativity: Beyond the myth of genius*. New York, NY: WH Freeman.

Routledge
Taylor & Francis Group

Creativity Research Journal

ISSN: 1040-0419 (Print) 1532-6934 (Online) Journal homepage: http://www.tandfonline.com/loi/hcrj20

Intelligence Level and the Allocation of Resources for Creative Tasks: A Pupillometry Study

Amitash Ojha, Bipin Indurkhya & Minho Lee

To cite this article: Amitash Ojha, Bipin Indurkhya & Minho Lee (2017) Intelligence Level and the Allocation of Resources for Creative Tasks: A Pupillometry Study, Creativity Research Journal, 29:1, 78-85, DOI: 10.1080/10400419.2017.1263502

To link to this article: http://dx.doi.org/10.1080/10400419.2017.1263502

Published online: 02 Feb 2017.