Meta-Analysis of the Relationship Between Semantic Distance and Creative Thinking

Authors: Li Yadan, Du Ying, Xie Cong, Chunyu Liu, Yang Yilong, Li Yangping, Qiu Jiang, Li Yadan, QIU Jiang

Date: 2022-11-20T14:11:46+00:00

Abstract

The development of natural language processing has provided reliable and effective research methods for investigating the relationship between semantic distance and creative thinking. In recent years, research on this relationship has gradually increased, yet conclusions remain inconsistent. Based on creativity association theory and the spreading activation model, this study employs meta-analysis to examine the overall relationship between semantic distance and creative thinking, and analyzes the reasons for inconsistent findings in previous research. Through literature retrieval and screening, 14 studies were obtained, with r-values extracted as effect sizes (53 effect sizes in total, 4,729 independent samples), and a meta-analysis was conducted using a random-effects model. The results demonstrate a moderate positive correlation between semantic distance and creative thinking (r = 0.379, 95%CI [0.300, 0.452]); the strength of this correlation is moderated by participants' age and different measurement indicators of creative thinking. The findings indicate that semantic distance is closely related to creative thinking, while also explaining the reasons for inconsistent conclusions in prior studies. These results not only provide new research perspectives and theoretical explanations for deeper investigation into the cognitive neural mechanisms of creative thinking, but also contribute to a more comprehensive understanding of the relationship between semantic distance and creative thinking and its boundary conditions, offering scientific basis and important insights for better explaining, predicting, and enhancing creativity.

Full Text

A Meta-Analysis of the Relationship Between Semantic Distance and Creative Thinking

Li Yadan[1], Du Ying[1], Xie Cong[1], Liu Chunyu[1], Yang Yilong[2], Li Yangping[1], Qiu Jiang[3],[4]

[1]Key Laboratory of Modern Teaching Technology (Shaanxi Normal University), Ministry of Education, Xi'an 710062, China
[2]School of English Studies, Xi'an International Studies University, Xi'an 710019, China
[3]Key Laboratory of Cognition and Personality (Southwest University), Ministry of Education, Chongqing 400715, China
[4]Faculty of Psychology, Southwest University, Chongqing 400715, China

Abstract: The development of natural language processing has provided reliable and effective research methods for exploring the relationship between semantic distance and creative thinking. In recent years, research on this relationship has gradually increased, yet findings remain inconsistent. Based on the Associative Theory of Creativity and the Spreading-Activation Model, this study employed meta-analysis to examine the overall relationship between semantic distance and creative thinking and to analyze the reasons for inconsistent conclusions in previous research. After literature retrieval and screening, 14 studies were obtained, with r-values extracted as effect sizes (53 effect sizes total, 4,729 independent samples). A random-effects model was used for the meta-analysis.

The results showed a moderate positive correlation between semantic distance and creative thinking (r = 0.379, 95%CI [0.300, 0.452]). The strength of this correlation was moderated by participants' age and the specific measurement indicators used for creative thinking. These findings indicate that semantic distance is closely related to creative thinking while explaining the reasons for inconsistent results in previous studies. The results not only provide new research perspectives and theoretical explanations for deeper investigation into the cognitive and neural mechanisms of creative thinking, but also contribute to a more comprehensive understanding of the relationship between semantic distance and creative thinking and its boundary conditions, offering scientific evidence and important implications for better explaining, predicting, and enhancing creativity.

Keywords: creative thinking, semantic distance, creativity measurement, meta-analysis

Funding: This research was supported by the Youth Fund Project of Humanities and Social Sciences Research of the Ministry of Education (22XJC190001), the General Project of Natural Science Basic Research Program of Shaanxi Province (2022JQ-156), and the Shaanxi Provincial Philosophy and Social Science Major Theoretical and Practical Issues Research Project "A Study on University Teachers' Evaluation of Students' Innovative Ideas in Shaanxi from the Perspective of Educational Neuroscience."

Corresponding Authors: Qiu Jiang, E-mail: qiuj318@swu.edu.cn; Li Yadan, E-mail: liyadan@snnu.edu.cn

1.1 Creative Thinking and Its Measurement

Creative thinking represents a high-level cognitive activity with profound impact on scientific progress and social development, with one of its core cognitive components being associative ability based on semantic memory (Acar & Runco, 2014; Marron et al., 2018). This associative ability is manifested through semantic distance—the degree of relatedness between concepts (Benedek & Neubauer, 2013; Beaty et al., 2014). Consequently, semantic distance serves as an important tool for understanding creative thinking and creative cognitive processes.

The rapidly developing field of network science has provided a reliable and effective quantitative methodology for studying complex human cognitive systems (Baronchelli et al., 2013; Siew et al., 2019). In cognitive science, researchers typically utilize semantic networks constructed from mental lexicons to represent semantic memory structure (Christensen & Kenett, 2021). In such networks, concepts are represented as nodes connected by edges, while semantic distance quantifies the proximity between concepts—that is, their semantic similarity (Paulsen et al., 1996). Research applying semantic networks to creative thinking has demonstrated that examining semantic network properties is a promising approach for exploring creativity (Kenett et al., 2018), though effectively integrating semantic networks and semantic distance to reveal creative thinking processes remains an area for further investigation (Kenett & Faust, 2014).

In empirical research, divergent thinking tests are commonly used to measure creative thinking, yet these tests have several limitations. For instance, the high correlation between fluency and uniqueness scores often leads to confounded results, and uniqueness scoring depends heavily on sample characteristics (Silvia et al., 2008). Therefore, beyond optimizing existing measurement techniques, there is a need to enhance the objectivity and accuracy of creativity assessment. Some scholars have proposed using semantic distance to measure creative thinking, though the validity of this approach remains controversial (Marron et al., 2018; Wang et al., 2018).

Employing semantic distance as an indicator to quantify creative thinking processes, investigate the cognitive and neural mechanisms of creativity, and develop creative assessment and enhancement tools based on semantic distance thus represents an important frontier with pioneering significance in the field.

In summary, this meta-analysis aims to clarify the relationship between semantic distance and creative thinking, introduce new measurement methods for studies examining the association between individual associative ability and creative thinking, and establish a more solid theoretical foundation for research on creative thinking processes and the relationship between semantic memory structure and creative thinking.

Divergent thinking, defined as the mental capacity to generate multiple original ideas in response to a given problem or prompt (Acar & Runco, 2019; Forthmann, Wilken, et al., 2019), has long been a central focus in creative thinking research (Hocevar, 1980). Divergent thinking tests represent the most frequently used and widely applied assessment format in creativity research (Plucker & Makel, 2010; Reiter-Palmon et al., 2019). Among these, Guilford's (1950) Alternate Uses Task (AUT) and Torrance's (1972) Torrance Tests of Creative Thinking (TTCT) have been particularly prominent. Divergent thinking typically comprises four dimensions: fluency (the number of ideas generated), flexibility (the diversity of ideas), originality (the unusualness or uniqueness of ideas), and elaboration (the level of detail in responses) (Torrance, 1965, 1988). Scoring procedures for divergent thinking tests generally evaluate these four dimensions to assess participants' creative performance.

Despite their widespread use, traditional divergent thinking tests have notable drawbacks. First, they fail to provide researchers with tools to further investigate creative thinking processes (Hass, 2017; Marron et al., 2018). Second, among the four main scoring indicators, only fluency can be objectively measured; traditional scoring methods for flexibility, originality, and elaboration suffer from various limitations, such as potential positive bias that may inflate creativity scores beyond true levels or introduce additional error due to different raters' scoring criteria (Bossomaier et al., 2009; Lee, 2008). Third, scoring for divergent thinking tests often confounds fluency and originality, as originality scores tend to increase with fluency scores (Clark & Mirels, 1970; Hocevar & Michael, 1979; Silvia, 2015; Silvia et al., 2008) or decrease with larger sample sizes (Silvia, 2015). These issues have raised concerns about the objectivity, reliability, validity, and normative standards of divergent thinking tests (Benedek & Neubauer, 2012).

To further explore the nature, mechanisms, and interactions of creative thinking with various factors, a new measurement technique is needed—one that can both investigate creative thinking processes and more objectively and efficiently quantify creative products. Using semantic distance to measure creative thinking or improve scoring methods for creativity tests represents a promising approach that meets these requirements.

1.2 The Relationship Between Semantic Distance and Creative Thinking

The concept of semantic distance originates from Collins and Loftus's (1975) Spreading-Activation Model. According to this model, concepts sharing more definitional features are more closely related, and this relationship is termed semantic distance (Volle, 2018). For example, "snow" and "white" frequently co-occur in text, resulting in a small semantic distance, whereas "snow" and "oil" rarely appear together, yielding a larger semantic distance.

Mednick (1962) proposed the Associative Theory of Creativity, which explains the relationship between creative thinking and semantic memory structure (Mednick, 1962). This theory posits that creative thinking involves connecting weakly related or distant concepts into novel and useful combinations. The greater the semantic distance between concepts, the more creative and novel the resulting combination. Building on Mednick's (1962) theory, Benedek et al. (2012) proposed that dissociative ability and associative combination ability are fundamental cognitive capacities closely related to creative thinking. Dissociative ability refers to the capacity to generate unrelated concepts, which can be understood as a form of semantic inhibition that facilitates access to semantically distant concepts. Associative combination ability involves forming reasonable associations between seemingly unrelated concepts. We can thus infer that semantic distance, as a quantitative indicator of relationships between concepts (Volle, 2018) and a measure of individual associative ability, can effectively reflect creative thinking based on associative processes. The Spreading-Activation Model also suggests that creative individuals possess more complex (Collins & Loftus, 1975; Gruszka & Necka, 2002; Kenett, 2019) and more flexible semantic networks (Schilling, 2005).

In recent years, semantic distance has been adopted as an indicator of creative performance. Researchers investigating state creativity (Green et al., 2012; Prabhakaran et al., 2013; Weinberger et al., 2016) have used semantic distance as a measure of creativity levels, where state creativity refers to varying levels of creativity exhibited by participants under different instructions or cue conditions. Studies employing semantic distance to measure creative thinking have demonstrated better discriminant validity and structural reliability across various creativity indicators compared to traditional methods (Dumas & Dunbar, 2014).

Furthermore, applying semantic distance enables researchers to achieve more objective understanding of creative thinking quality and better investigate its cognitive and neural mechanisms. Creative thinking is widely believed to require the coupling of associative processes with executive processes (Silvia et al., 2013). However, most creative thinking tasks have not distinguished between these two cognitive processes (Mednick, 1968; Runco et al., 2016), and differentiating them could enhance our understanding of creative thinking and cognition (Fox et al., 2015). As an indicator of associative ability, semantic distance can better reflect the associative processes involved in creative thinking tasks (Beaty, Nusbaum, et al., 2014; Beaty, Silvia, et al., 2014; Marron et al., 2018). Consequently, semantic distance has been used as a measurement index for creative thinking in cognitive neuroscience research, allowing comparison of brain activation patterns when individuals generate answers at different creativity levels (Beaty et al., 2017; Green et al., 2015; Tempest & Radel, 2019), examination of dynamic changes in creative performance over time (Green, 2016), and investigation of individual differences in creativity (Green, 2016).

Beyond measuring creativity from a semantic network perspective, semantic distance has also been used to improve scoring methods for traditional creative thinking tests such as the AUT (Volle, 2018). Semantic distance can quantify divergent thinking scores while avoiding confounding between originality and flexibility (Acar & Runco, 2015) and can characterize specific dimensions of creative thinking like flexibility (Johnson et al., 2019) and originality (Beaty et al., 2020). Many researchers believe this corpus-based computational model and automated scoring method effectively avoids subjective rater bias, enhances scoring standardization and objectivity, and substantially saves time and labor costs while improving scoring efficiency (Acar & Runco, 2015; Beaty & Johnson, 2020; Johnson et al., 2019).

Despite substantial evidence supporting a correlation between creativity and semantic distance, some studies have failed to replicate this relationship. As early as 1973, researchers found that although highly creative individuals responded faster in free association tasks than less creative individuals, the ability to generate novel words or word combinations might not be related to creativity (Rothenberg, 1973). Subsequently, Benedek and Neubauer (2013) found that the probability of associations between words could not distinguish high- from low-creativity individuals when testing the Associative Theory of Creativity. Highly creative individuals do not necessarily exhibit larger semantic distances in their associative processes (Marron & Faust, 2018). More recent studies have provided direct evidence, finding no significant correlation between semantic distance and creative thinking (Marron et al., 2018; Wang et al., 2018).

In summary, while the Associative Theory of Creativity has received considerable empirical support (Benedek et al., 2012; Kenett et al., 2014; Kleinmintz et al., 2019; Rossmann & Fink, 2010), some studies have found no significant relationship between semantic distance and creative thinking (Marron et al., 2018; Wang et al., 2018). Therefore, whether semantic distance, as a quantitative indicator of conceptual relationships, can effectively reflect individual creative thinking requires further investigation and validation.

1.3 Moderating Variables in the Relationship Between Semantic Distance and Creative Thinking

Recent studies on the relationship between semantic distance and creative thinking have yielded inconsistent results, possibly due to demographic factors (such as age) and the specific measurement indicators used to assess creative thinking.

Based on existing research, age may influence the relationship between semantic distance and creative thinking. First, age is associated with language ability and vocabulary size. Older adults possess richer vocabulary and semantic knowledge than younger adults (Kavé & Halamish, 2015; Verhaeghen & Paul, 2003), and individuals with stronger language abilities and larger vocabularies are less constrained by expressive limitations when generating ideas, often performing better on verbal creativity tasks. Stronger language ability may also provide more cognitive resources for creative idea generation (Wu et al., 2005). Second, semantic structure and semantic memory differ across age groups. For example, concepts in older adults' semantic memory are more modular and dispersed (Dubossarsky et al., 2017; Wulff et al., 2019; Zortea et al., 2014), meaning older adults' semantic networks are more sparsely structured than those of younger adults, with fewer connections between concepts and greater semantic distances. Dubossarsky et al. (2017) further evaluated differences in semantic networks across the lifespan (ages 10-84), finding nonlinear development of semantic memory. Children's semantic structures are relatively sparse, density increases through middle age, then becomes sparser again in older adulthood. Consequently, younger adults' semantic networks based on semantic memory are more flexible than older adults', and more flexible semantic networks often indicate higher creative thinking ability (Kenett et al., 2014; Rossmann & Fink, 2010). Similarly, research has found that creative thinking ability declines with age (Leon et al., 2019; Simon & Bock, 2016; Zhang & Niu, 2013). Therefore, participants' age may moderate the relationship between semantic distance and creative thinking.

Additionally, because creative thinking can be measured through diverse indicators, the specific measurement index used in a study may affect the relationship between semantic distance and creative thinking. While semantic distance can reflect creative thinking overall, its predictive power may vary across different indicators (originality, fluency, elaboration, and flexibility). Forster and Dunbar (2009) found that originality scores derived from semantic distance analysis better predicted individual innovation ability than other common divergent thinking measures (fluency, flexibility, and elaboration). Flexibility, which involves the ability to shift perspectives when solving problems and avoid conventional approaches, is crucial for creative problem-solving. Beketayev and Runco (2016) found that scores obtained through a Semantic-Based Algorithm (SBA) significantly correlated with flexibility scores from traditional divergent thinking test scoring. Elaboration, another dimension of creative thinking, represents the practicality or applicability of creative ideas. Runco and Pritzker (1999) proposed that refining and improving creative ideas enhances their quality. However, for semantic distance, because participants' responses in creative thinking tasks may vary in detail level (i.e., their elaboration), semantic distance-based scoring may be affected by these differences (Forthmann, Oyebade, et al., 2019).

In summary, previous controversies have centered on whether semantic distance can effectively measure creative thinking, and prior research has not comprehensively examined potential influencing factors. Given that measuring creative thinking effectively is fundamental to creativity research and application, clarifying the relationship between semantic distance and creative thinking has important implications for creative thinking assessment, development, and training. However, no study has yet integrated and examined this relationship from a comprehensive perspective. Therefore, this study employs meta-analysis to systematically investigate the relationship between semantic distance and creative thinking and to explore potential moderating variables. Theoretically, this will help resolve existing controversies, provide a more complete and accurate understanding of their relationship, offer scientific evidence for developing and integrating creative thinking theories, and serve as a valuable supplement to creativity measurement research. Practically, it will help reveal the specific conditions under which semantic distance relates to creative thinking, provide new approaches for creative thinking assessment, and offer more targeted and precise personalized training programs and interventions for effectively enhancing creative thinking and cultivating innovative talent.

2.1 Literature Search

This study comprehensively searched Chinese and English literature published before October 2021 that examined the relationship between semantic distance and creative thinking, with a secondary update conducted in December 2021. Chinese literature was searched in the following databases: China National Knowledge Infrastructure (CNKI), Wanfang Data Knowledge Service Platform, VIP Chinese Journal Service Platform, China Doctoral Dissertations Full-text Database, and China Master's Theses Full-text Database, using keyword combinations such as "semantic distance," "semantic network," "latent semantic analysis," "creativity," "creative thinking," "creativity measurement," "divergent thinking," and "divergent thinking measurement." English literature was searched in Springer Link, Science Direct, Wiley Online Library, ProQuest, Google Scholar, and Web of Science using keyword combinations including "semantic distance," "LSA," "creativity," "innovation," "divergent thinking," "semantic networks," and "semantic." Additionally, the reference lists of all included studies, relevant review articles, and empirical papers were traced using a citation 回溯法 (backward search) method to ensure no relevant literature was omitted. The initial search yielded 141 relevant articles.

2.2 Literature Inclusion and Exclusion Criteria

The retrieved literature was screened according to the following criteria (see Figure 1 [Figure 1: see original paper]): (1) Studies must be empirical investigations of the relationship between semantic distance and creative thinking, excluding purely theoretical discussions and literature reviews; (2) Complete data with clear sample sizes; (3) Examination of the relationship between semantic distance and creative thinking with explicitly reported correlation coefficients or convertible statistics (r-values or F-values, t-values, or ^{2} values that could be transformed into r-values), excluding data obtained through structural equation modeling, regression analysis, or other statistical methods; (4) No duplicate data across studies—if multiple publications used the same dataset, only one was included. Ultimately, 14 studies meeting meta-analysis criteria were obtained, comprising 53 independent effect sizes and 4,729 samples.

2.3 Literature Quality Assessment

Literature quality was assessed using criteria established by Zhang et al. (2019), including participant selection, data validity rates, internal consistency reliability of measurement tools, and journal tier. The quality assessment was conducted independently by two raters, yielding an inter-rater consistency Kappa value of 0.946. According to Kappa interpretation standards: 0.40-0.59 indicates fair agreement, 0.60-0.74 indicates good agreement, and 0.75 or above indicates excellent agreement (Orwin & Vevea, 1994). Thus, the inter-rater consistency in this study reached a high level.

2.4 Literature Feature Coding

The included studies were coded as follows (see Table 1): publication information (author names, publication year), sample size, mean age of participants, effect size Zr, and creative thinking measurement indicators (fluency, flexibility, elaboration, originality). Effect size extraction followed these criteria: (1) Each independent sample was coded once; if a paper reported multiple independent samples, they were coded separately; (2) If an independent sample had two statistical indicators, the more conservative (less significant) indicator was selected; (3) Correlation coefficients were transformed into Fisher's Z values based on normal distribution principles; (4) Duplicate publications were counted only once. Two coders independently coded according to the inclusion and exclusion criteria, achieving 95.2% coding consistency, indicating effective and accurate literature coding.

2.5 Data Processing and Analysis

This study used Comprehensive Meta-Analysis 3.0 (CMA3.0) for data processing and analysis. First, Q-tests and I^2 tests were conducted for heterogeneity testing. Based on heterogeneity test results, the appropriateness of the selected meta-analysis model was verified. The Q-test formula is: , where Zri is the ith effect size and SE is the standard error of the mean effect size (Borenstein et al., 2010). Second, the selected model was used to calculate and combine effect sizes. Third, moderator effect tests including subgroup analysis and meta-regression analysis were performed. If moderator effects were non-significant, JASP software was used to estimate Bayes factors to further test whether results supported the null hypothesis. Finally, publication bias was examined using funnel plots, fail-safe numbers (Nfs; Viechtbauer, 2007), and Egger's regression test (Egger et al., 1997).

2.5.1 Effect Sizes

The meta-analysis used correlation coefficients (r) between semantic distance and creative thinking as effect sizes. If some studies did not directly report correlation coefficients but reported F-values, t-values, or ^{2} values, CMA3.0 software was used to calculate and synthesize these into correlation coefficients.

2.5.2 Model Selection

Random-effects and fixed-effects models are commonly used in meta-analysis. Fixed-effects models assume a single true effect size across all studies, with observed differences attributed to random error. Random-effects models allow for different effect sizes across studies (Kisamore & Brannick, 2008). For example, studies with older, more educated, or healthier participants, or those using more intensive interventions, may yield higher (or lower) effect sizes (Borenstein et al., 2010; Nikolakopoulou et al., 2014). Specifically, if the meta-analysis focuses solely on the relationship between independent and dependent variables without considering other variables, a fixed-effects model is appropriate. However, if participant characteristics, measurement tools, or experimental paradigms may influence results, a random-effects model is more reasonable (Borenstein et al., 2010). In this study, participants' age and creative thinking measurement indicators could influence the relationship between semantic distance and creative thinking, so a random-effects model was selected, with heterogeneity tests used to evaluate model reliability (Nikolakopoulou et al., 2014).

3.1 Heterogeneity Test

Heterogeneity test results for effect sizes are shown in Table 2 . The Q-value was 667.359 ($p < 0.001$), indicating substantial heterogeneity among effect sizes and supporting the use of a random-effects model to combine effect sizes (Nikolakopoulou et al., 2014). To compensate for the Q-test's inability to assess heterogeneity magnitude, I^2 tests were also conducted. Higgins et al. (2003) suggested that I^2 values of 25%, 50%, and 75% represent low, moderate, and high heterogeneity, respectively. In this study, I^2 was 92.21, indicating that 92.21% of total variance was due to true differences between effect sizes, representing high heterogeneity that aligns with Q-test results. The Tau-squared value was 0.092, suggesting that 9.2% of variance between studies could be used to calculate weights. These results also suggest potential moderating variables in the relationship between semantic distance and creative thinking, necessitating further analysis of moderator effects.

3.2 Publication Bias Test

3.2.1 Funnel Plot

Funnel plots were first used to examine publication bias. As shown in Figure 2 [Figure 2: see original paper], studies on the relationship between semantic distance and overall creative thinking and its dimensions were basically symmetrically distributed and concentrated in the upper middle region, indicating no severe publication bias (Light & Pillemer, 1984). However, to overcome the subjectivity of visual asymmetry assessment, Egger's regression (Egger et al., 1997; Macaskill et al., 2010) or fail-safe number methods (Rosenthal & Robert, 1979) were used for further publication bias testing (Terrin et al., 2005).

3.2.2 Egger's Regression Test

Egger's regression test establishes a linear regression equation with standardized effect size as the dependent variable and effect estimate precision as the independent variable. An intercept close to 0 suggests minimal publication bias;

an intercept of 0 indicates no publication bias (Egger et al., 1997). Whether the intercept equals 0 can be tested through Egger's regression intercept hypothesis testing. Egger's test showed an intercept of 1.249, $p = 0.205 > 0.05$, indicating minimal likelihood of publication bias affecting results.

3.2.3 Fail-Safe Number Method

The fail-safe number represents the minimum number of unpublished studies required to reverse meta-analysis results (Rosenthal & Robert, 1979). When this number exceeds 5K + 10 (where K is the number of effect sizes included, here K = 53), significant publication bias is unlikely (Hoeve et al., 2012). This study's fail-safe number was 1,269, far exceeding the critical value of 275. This result indicates that findings on the relationship between semantic distance and creative thinking and its dimensions are accurate and reliable, with minimal possibility of publication bias.

3.3 Sensitivity Analysis

Heterogeneity tests indicated high heterogeneity across effect sizes. Based on funnel plot visualization and effect size deviations, a stepwise deletion method (e.g., Li et al., 2016; Liu et al., 2020; Sun et al., 2020) was used for sensitivity analysis of heterogeneous effect sizes in the semantic distance-creative thinking relationship. Many meta-analyses use sensitivity analysis to evaluate result robustness and reliability (e.g., Greenhouse & Iyengar, 2009; Han et al., 2020). Using CMA3.0's "one study removed" function, sensitivity analysis revealed that after excluding any single sample, the effect size for the semantic distance-creative thinking relationship consistently ranged between 0.365 and 0.400, indicating high stability of meta-analysis results.

3.4 Main Effect Test

Due to high heterogeneity across studies, a random-effects model was used for main effect analysis (Kisamore & Brannick, 2008). Results showed a correlation coefficient of 0.379 between semantic distance and creative thinking (95%CI [0.300, 0.452], $Z = 8.745$, $p < 0.001$) (see Table 3), indicating a significant moderate positive correlation (Cohen, 1988).

3.5 Moderator Effect Test

This study used subgroup analysis for categorical variables and meta-regression analysis for continuous variables.

3.5.1 Moderating Effect of Participants' Age

Meta-regression analysis examined whether mean participant age significantly influenced the relationship between semantic distance and creative thinking.

Results showed a significant moderating effect of mean age (B = -0.0050, Z = -3.84, 95%CI [-0.0077, -0.0024]).

3.5.2 Moderating Effect of Creative Thinking Measurement Indicators

Measurement indicators in included studies comprised individual dimensions (fluency, flexibility, originality, elaboration) and composite total scores. Moderator tests showed significant moderation by creative thinking total scores and sub-dimensions ($Qb = 89.380$, $p < 0.001$) (see Table 4). Semantic distance showed significant positive correlations with fluency, flexibility, and originality dimensions, but a significant negative correlation with elaboration. Subsequent heterogeneity tests for correlations between semantic distance and each measurement indicator revealed significant heterogeneity for flexibility ($Qw = 63.436$, $p < 0.001$), originality ($Qw = 10.542$, $p = 0.014$), and fluency ($Qw = 25.666$, $p = 0.007$), but non-significant heterogeneity for elaboration, indicating high within-group homogeneity and combinability for the elaboration dimension.

4.1 Validity of Semantic Distance as a Measure of Creative Thinking

This study found a significant positive correlation between semantic distance and creative thinking ($r = 0.379$, $p < 0.001$), consistent with previous research (Hass, 2017; Heinen & Johnson, 2018). This result further validates Mednick's (1962) Associative Theory of Creativity, which proposes that greater semantic distance between concepts yields more creative and novel combinations. Semantic distance effectively quantifies relationships between concepts and thus reflects individuals' associative ability (Benedek & Neubauer, 2013). For example, in Prabhakaran et al.'s (2013) study examining state creativity, participants were prompted to generate creative versus non-creative associations, with differences in state creativity clearly reflected in variations in semantic distance. Gray et al. (2019) also successfully used semantic distance to quantify participants' associative ability and predict their creative performance. Additionally, most included studies measured creative thinking through classic divergent thinking tasks. As previously discussed, divergent thinking tasks require participants to consider unconventional, novel uses for common objects—a task demanding associative ability that has been confirmed in numerous studies (Hass, 2017; Marron et al., 2018; Wang et al., 2018). Originality, as one evaluation dimension of divergent thinking tasks, has traditionally been calculated based on the probability of a particular answer appearing across all responses (Acar & Runco, 2015). This scoring logic is similar to semantic distance calculation, but semantic distance offers superior objectivity. Probability-based quantification depends on existing answer databases, which vary across studies, causing the same answer to have different frequencies due to participant groups, culture, and other factors. Semantic distance quantifies divergent thinking responses using a unified corpus, and while the corpus and algorithms may affect specific results, the generalizability and objectivity are substantially improved compared to traditional methods (Acar & Runco, 2019). In conclusion, at the theoretical level, semantic distance effectively reflects associative ability—the core component of creative thinking. At the operational level, its objective measurement of originality complements traditional methods.

Neuroimaging research also provides indirect evidence for the semantic distance-creative thinking relationship. From a brain network perspective, creative thinking is closely related to neural activity in the default mode network (DMN) and executive control network (ECN) (Beaty et al., 2015). Core regions of the DMN are associated with semantic and episodic memory (Marron & Faust, 2018). The ECN can inhibit common, non-creative responses, facilitating access to more remotely associated concepts (Benedek & Neubauer, 2013). At the regional level, a neural marker of creative thinking is activation of the left inferior frontal gyrus (IFG) (see Chen et al., 2020), which researchers believe supports semantic memory retrieval (Badre & Wagner, 2007; Chen et al., 2021) and generation of remote associations during creative thinking (Ralph et al., 2017). Green et al. (2015) also found that frontopolar cortex activation is not only closely related to creative performance but is also a key brain region for perceiving semantic distance (Green et al., 2012).

These findings suggest that cognitive and neural activities related to semantic distance share similarities with the brain mechanisms underlying creative thinking. Moreover, as a continuous variable, semantic distance can more precisely reflect quantitative variations in creative thinking rather than simple binary comparisons (e.g., creative vs. non-creative conditions) (Kenett, 2018; Kenett, 2019; Kenett et al., 2017). Therefore, semantic distance offers unique advantages for measuring creative thinking and is more suitable for neuroimaging research than traditional creative thinking measures (Green, 2016).

However, this study found an effect size of 0.379 for the semantic distance-creative thinking relationship, representing only a moderate magnitude (Cohen, 1988). This suggests that while semantic distance has some validity in measuring creative thinking, its representational capacity for creative thinking is limited. Several factors may explain this. First, semantic distance is a text-based measure, and its relationship with non-verbal creative thinking test results is not strong (Green et al., 2015). Second, creative thinking involves not only bottom-up associative processes but also top-down executive control processes (Benedek et al., 2017). Semantic distance primarily relates to free association processes, inevitably providing insufficient examination of executive control processes (Marron et al., 2018), thereby reducing its explanatory power for creative thinking. Third, creative thinking is influenced by both associative ability and information retrieval capacity (Kenett et al., 2014). Using semantic distance alone to investigate individual creative thinking may have limited predictive power. Therefore, further theoretical and empirical investigation is needed regarding the use of this objective new indicator to represent creative thinking.

4.2 Moderating Effects in the Relationship Between Semantic Distance and Creative Thinking

This study found that participants' age significantly moderated the relationship between semantic distance and creative thinking, indicating that the relationship varies across age groups. Specifically, the correlation gradually decreased with increasing age. This may occur because age-related changes in semantic memory structure and knowledge storage affect the relationship. First, semantic memory structure becomes sparser with age (Dubossarsky et al., 2017; Wulff et al., 2019; Zortea et al., 2014), leading to smaller semantic distances between responses and prompts in older adults. In this case, semantic distance shows reduced correlation with creative thinking and cannot fully represent creative thinking ability. Second, changes in knowledge storage and life experience may play a role. Common verbal creative thinking tasks require certain knowledge reserves (Wu et al., 2005). Problem-solving ability in real-world contexts increases with age (Shimonaka & Nakazato, 2007), though language ability may not follow the same pattern (Ruth & Birren, 1985). This means that older adults' novel responses in creative tasks may stem from previous experience and knowledge rather than creative thinking per se. Thus, although responses may show large semantic distances from prompts, creative thinking is not the sole contributor, and the correlation between semantic distance and creative thinking decreases with age. These findings suggest that future research should conduct longitudinal studies to verify these conclusions and more effectively reveal the relationship between semantic distance and creative thinking.

Our meta-analysis also showed that correlation coefficients between semantic distance and creative thinking differ across measurement indicators. Semantic distance showed significant positive correlations with flexibility and originality, with a stronger correlation for flexibility and weaker correlation for originality. Additionally, semantic distance showed a significant negative correlation with elaboration. These results indicate that creative thinking measurement indicators moderate the relationship, likely because different indicators assess distinct aspects of creative thinking. The highest correlation with flexibility may reflect that flexibility involves switching between domains and changing problem-solving approaches (Guilford, 1950). Higher flexibility is crucial for generating ideas and may produce more creative responses (Goncalves et al., 2013). When highly flexible individuals encounter specific words, they generate more ideas from different categories or uses, reducing conceptual associations and increasing semantic distance. The moderate negative correlation with elaboration may occur because responses to verbal creative thinking tasks vary in word count (i.e., elaboration level), affecting semantic distance-based scoring. Forthmann et al. (2018) argued that since semantic distance scores are calculated based on entire responses (phrases or short sentences composed of many words) rather than single words, function words and conjunctions (e.g., "and" or "so") may reduce overall semantic distance despite core responses having large semantic distances and high originality (Dumas et al., 2020).

4.3 Limitations and Future Directions

Previous research on the semantic distance-creative thinking relationship has yielded inconsistent results, yet no study has systematically examined this relationship. This meta-analysis preliminarily clarified controversies and the varying correlations between semantic distance and different creative thinking measurement indicators, revealing a moderate positive correlation. The findings partially support the Associative Theory of Creativity (Mednick, 1962) and provide references for future research. However, several limitations remain: First, research on this topic is still in its early stages, and this meta-analysis had a relatively small sample, though it provides objective evidence. Future meta-analyses with larger samples are needed. Second, many potential moderating variables exist, but this study only examined two primary factors based on existing literature. Other variables, such as different databases and algorithms, may affect the relationship (Beaty & Johnson, 2020; Dumas et al., 2020).

This study offers several implications for future research. First, given that participants' age and creative thinking measurement indicators influence the relationship, future studies should consider these variables. Second, deeper investigation and systematic summarization of the semantic distance-creative thinking relationship are needed (Orwig et al., 2021), such as examining relationships between semantic distance and associative abilities closely linked to creative thinking (e.g., associative fluency, associative flexibility, dissociative flexibility) (He et al., 2020) and their cognitive and neural mechanisms, as well as the influence of other higher-order cognitive functions (e.g., cognitive control, working memory). Third, most current research focuses on domain-general creativity; future studies should examine relationships between semantic distance and domain-specific creativity (e.g., scientific and artistic creativity) and their cognitive and neural mechanisms. Finally, at the methodological level, future research should systematically investigate relationships between semantic distance results derived from different corpora and computational methods and creative thinking to provide a more solid theoretical basis for creative thinking measurement.

5 Conclusions

This meta-analysis found a moderate positive correlation between semantic distance and creative thinking, moderated by participants' age and creative thinking measurement indicators. Specifically: (1) The correlation between semantic distance and creative thinking decreased with increasing participant age; (2) Flexibility showed a stronger correlation with semantic distance than originality and fluency, while elaboration was negatively correlated with semantic distance.

References

Acar, S., & Runco, M. A. (2014). Assessing associative distance among ideas *elicited by tests of divergent thinking. Creativity Research Journal, 26(2), 229–238.*

Acar, S., & Runco, M. A. (2015). Thinking in multiple directions: Hyperspace categories in divergent thinking. Psychology of Aesthetics, Creativity, and the Arts, 9(1), 41–53.

Acar, S., & Runco, M. A. (2019). Divergent thinking: New methods, recent research, and extended theory. Psychology of Aesthetics, Creativity, and the Arts, 13(2), 153–158.

Badre, D., & Wagner, A. D. (2007). Left ventrolateral prefrontal cortex and the cognitive control of memory. Neuropsychologia, 45(13), 2883–2901.

Baronchelli, A., Ferrer-i-Cancho, R., Pastor-Satorras, R., Chater, N., & Christiansen, M. H. (2013). Networks in cognitive science. Trends in Cognitive Sciences, 17(7), 348–360.

Beaty, R. E., Benedek, M., Barry Kaufman, S., & Silvia, P. J. (2015). Default and executive network coupling supports creative idea production. Scientific Reports, 5(1), 1–14.

Beaty, R. E., Christensen, A. P., Benedek, M., Silvia, P. J., & Schacter, D. L. (2017). Creative constraints: Brain activity and network dynamics underlying semantic interference during idea production. NeuroImage, 148, 189–196.

Beaty, R. E., & Johnson, D. R. (2020). Automating creativity assessment with SemDis: An open platform for computing semantic distance. Behavior Research Methods, 1–24.

Beaty, R. E., Nusbaum, E. C., & Silvia, P. J. (2014). Does insight problem solving predict real-world creativity? Psychology of Aesthetics, Creativity, and the Arts, 8(3), 287–292.

Beaty, R. E., Silvia, P. J., Nusbaum, E. C., Jauk, E., & Benedek, M. (2014). The roles of associative and executive processes in creative cognition. Memory & Cognition, 42(7), 1186–1197.

Beaty, R. E., Chen, Q. L., Christensen, A. P., Kenett, Y. N., Silvia, P. J., Benedek, M., & Schacter, D. L. (2020). Default network contributions to episodic and semantic processing during divergent creative thinking: A representational similarity analysis. Neuroimage, 209, 116499.

Beketayev, K., & Runco, M. A. (2016). Scoring divergent thinking tests by computer with a semantics-based algorithm. Europe's Journal of Psychology, 12(2), 210–220.

Benedek, M., Kenett, Y. N., Umdasch, K., Anaki, D., Faust, M., & Neubauer, A. C. (2017). How semantic memory structure and intelligence contribute to creative thought: A network science approach. Thinking & Reasoning, 23(2), 158–183.

Benedek, M., Könen, T., & Neubauer, A. C. (2012). Associative abilities underlying creativity. Psychology of Aesthetics, Creativity, and the Arts, 6(3), 273–281.

Benedek, M., & Neubauer, A. C. (2013). Revisiting Mednick's model on creativity-related differences in associative hierarchies. Evidence for a common path to uncommon thought. The Journal of Creative Behavior, 47(4), 273–289.

Borenstein, M., Hedges, L. V., Higgins, J. P. T., & Rothstein, H. R. (2010). A basic introduction to fixed effect and random effects models for meta-analysis. Research Synthesis Methods, 1(2), 97–111.

Bossomaier, T., Harré, M., Knittel, A., & Snyder, A. (2009). A semantic network approach to the creativity quotient (CQ). Creativity Research Journal, 21(1), 64–71.

Card, N. A. (2012). Applied Meta-Analysis for Social Science Research. New York, NY: Guilford Press.

Chen, L., Wu, J., Hartwigsen, G., Li, Z., Wang, P., & Feng, L. (2021). The role of a critical left fronto-temporal network with its right-hemispheric homologue in syntactic learning based on word category information. Journal of Neurolinguistics, 58, 100977.

Chen, Q., Beaty, R. E., & Qiu, J. (2020). Mapping the artistic brain: Common and distinct neural activations associated with musical, drawing, and literary creativity. Human Brain Mapping, 41(12), 3403–3419.

Christensen, A. P., & Kenett, Y. N. (2021). Semantic network analysis (SemNA): A tutorial on preprocessing, estimating, and analyzing semantic networks. Psychological Methods. Advance online publication.

Clark, P. M., & Mirels, H. L. (1970). Fluency as a pervasive element in the measurement of creativity. Journal of Educational Measurement, 7(2), 83–86.

Cohen, J. (1977). Statistical Power Analysis for the Behavioral Sciences. Salt Lake City, UT: Academic Press.

Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. Psychological Review, 82(6), 407–428.

Dubossarsky, H., De Deyne, S., & Hills, T. T. (2017). Quantifying the structure of free association networks across the life span. Developmental Psychology, 53(8), 1560–1570.

Dumas, D., & Dunbar, K. N. (2014). Understanding fluency and originality: A latent variable perspective. Thinking Skills and Creativity, 14, 56–67.

Dumas, D., Organisciak, P., & Doherty, M. (2020). Measuring divergent thinking originality with human raters and text-mining models: A psychometric comparison of methods. Psychology of Aesthetics, Creativity, and the Arts, 15(4), 645–663.

Egger, M., Davey Smith, G., Schneider, M., & Minder, C. (1997). Bias in meta-analysis detected by a simple, graphical test. British Medical Journal, 315(7109), 629–634.

Forster, E. A., & Dunbar, K. N. (2009). Creativity evaluation through latent semantic analysis. Proceedings of the Annual Conference of the Cognitive Science Society, 2009, 602–607.

Forthmann, B., Oyebade, O., Ojo, A., Günther, F., & Holling, H. (2018). Application of latent semantic analysis to divergent thinking is biased by elaboration. Journal of Creative Behavior, 53(4), 559–575.

Forthmann, B., Oyebade, O., Ojo, A., Günther, F., & Holling, H. (2019). Application of latent semantic analysis to divergent thinking is biased by elaboration. The Journal of Creative Behavior, 53(4), 559–575.

Forthmann, B., Wilken, A., Doebler, P., & Holling, H. (2019). Strategy induction enhances creativity in figural divergent thinking. The Journal of Creative Behavior, 53, 18–29.

Fox, K. C. R., Spreng, R. N., Ellamil, M., Andrews-Hanna, J. R., & Christoff, K. (2015). The wandering brain: Meta-analysis of functional neuroimaging studies of mind-wandering and related spontaneous thought processes. NeuroImage, 111, 611–621.

Goncalves, M., Cardoso, C., & Badke-Schaub, P. (2013). Inspiration peak: Exploring the semantic distance between design problem and textual inspirational stimuli. International Journal of Design Creativity and Innovation, 1(4), 215–232.

Gray, K., Anderson, S., Chen, E. E., Kelly, J. M., Christian, M. S., Patrick, J., Huang, L., Kenett, Y. N., & Lewis, K. (2019). "Forward Flow": A new measure to quantify free thought and predict creativity. American Psychologist, 74(5), 539–554.

Green, A. E., Cohen, M. S., Raab, H. A., Yedibalian, C. G., & Gray, J. R. (2015). Frontopolar activity and connectivity support dynamic conscious augmentation of creative state. Human Brain Mapping, 36(3), 923–934.

Green, A. E. (2016). Creativity, within reason: Semantic distance and dynamic state creativity in relational thinking and reasoning. Current Directions in Psychological Science, 25(1), 28–35.

Green, A. E., Cohen, M. S., Kim, J. U., & Gray, J. R. (2012). An explicit cue improves creative analogical reasoning. Intelligence, 40(6), 598–603.

Greenhouse, J. B., & Iyengar, S. (2009). Sensitivity analysis and diagnostics. In H. Cooper, L. V. Hedges, & J. C. Valentine (Eds.), The Handbook of Research Synthesis and Meta-Analysis (2nd ed., pp. 417–433). New York, NY: Russell Sage Foundation.

Gruszka, A., & Necka, E. (2002). Priming and acceptance of close and remote associations by creative and less creative people. Creativity Research Journal, 14(2), 193–205.

Guilford, J. P. (1950). Creativity. American Psychologist, 5(9), 444–454.

Han, L., Wang, C., Yao, D., Wang, B., Zhang, Z., & Liu, J. (2020). Clinical efficacy and safety of Danhong injection for the treatment of chronic heart failure: A protocol for systematic review. Medicine, 99(14), e19526.

Hass, R. W. (2017). Tracking the dynamics of divergent thinking via semantic distance: Analytic methods and theoretical implications. Memory & Cognition, 45(2), 233–244.

He, L., Kenett, Y. N., Zhuang, K., Liu, C., Zeng, R., Yan, T., Huo, T., & Qiu, J. (2020). The relation between semantic memory structure, associative abilities, and verbal and figural creativity. Thinking & Reasoning, 1–26.

Heinen, D. J., & Johnson, D. R. (2018). Semantic distance: An automated measure of creativity that is novel and appropriate. Psychology of Aesthetics, Creativity, and the Arts, 12(2), 144–156.

Higgins, J. P. T., Thompson, S. G., Deeks, J. J., & Altman, D. G. (2003). Measuring inconsistency in meta-analyses. British Medical Journal, 327(7414), 557–560.

Hocevar, D. (1980). Intelligence, divergent thinking, and creativity. Intelligence, 4(1), 25–40.

Hocevar, D., & Michael, W. B. (1979). The effects of scoring formulas on the discriminant validity of tests of divergent thinking. Educational and Psychological Measurement, 39(4), 917–921.

Hoeve, M., Stams, G. J. J. M., van der Put, C. E., Dubas, J. S., van der Laan, P. H., & Gerris, J. R. M. (2012). A meta-analysis of attachment to parents and delinquency. Journal of Abnormal Child Psychology, 40(5), 771–785.

Johnson, D. R., Cuthbert, A. S., & Tynan, M. E. (2019). The neglect of idea diversity in creative idea generation and evaluation. Psychology of Aesthetics, Creativity, and the Arts, 15(1), 125–135.

Kaufman, J. C., & Sternberg, R. J. (2010). The Cambridge Handbook of Creativity. Cambridge University Press.

Kavé, G., & Halamish, V. (2015). Doubly blessed: Older adults know more vocabulary and know better what they know. Psychology and Aging, 30(1), 68–73.

Kenett, Y. N. (2018). Going the extra creative mile: The role of semantic distance in creativity—Theory, research, and measurement. In R. E. Jung & O. Vartanian (Eds.), The Cambridge Handbook of the Neuroscience of Creativity (pp. 233–248). Cambridge University Press.

Kenett, Y. N., Anaki, D., & Faust, M. (2014). Investigating the structure of semantic networks in low and high creative persons. Frontiers in Human Neuroscience, 8, 407.

Kenett, Y. N. (2019). What can quantitative measures of semantic distance tell us about creativity? Current Opinion in Behavioral Sciences, 27, 11–16.

Kenett, Y. N., Levi, E., Anaki, D., & Faust, M. (2017). The semantic distance task: Quantifying semantic distance with semantic network path length. Journal of Experimental Psychology: Learning, Memory, and Cognition, 43(9), 1470–1485.

Kenett, Y. N., Levy, O., Kenett, D. Y., Stanley, H. E., Faust, M., & Havlin, S. (2018). Flexibility of thought in high creative individuals represented by percolation analysis. Psychological and Cognitive Sciences, 115(5), 867–872.

Kisamore, J. L., & Brannick, M. T. (2008). An illustration of the consequences of meta-analysis model choice. Organizational Research Methods, 11(1), 35–53.

Kleinmintz, O. M., Ivancovsky, T., & Shamay-Tsoory, S. G. (2019). The two-fold model of creativity: The neural underpinnings of the generation and evaluation of creative ideas. Current Opinion in Behavioral Sciences, 27, 131–138.

Lee, C. S. (2008). Commentary: Reliability and validity of uniqueness scoring in creativity assessment. Psychology of Aesthetics, Creativity, and the Arts, 2(2), 103–108.

Leon, S. A., Altmann, L. J. P., Abrams, L., Rothi, L. J. G., & Heilman, K. M. (2019). Novel associative processing and aging: Effect on creative production. Aging, Neuropsychology, and Cognition, 26(6), 877–891.

Li, D., Yang, D.-L., An, J., Jiao, J., Zhou, Y.-M., Wu, Q.-J., & Wang, X.-X. (2016). Effect of assisted hatching on pregnancy outcomes: A systematic review and meta-analysis of randomized controlled trials. Scientific Reports, 6, 31228.

Light, R. J., & Pillemer, D. B. (1984). Quantitative Procedures. In Summing Up: The Science of Reviewing Research (pp. 53–76). Harvard University Press.

Liu, M., Wang, Y., Li, J., Zhuang, X., Chen, X., Li, X., Liao, X., & Wang, L. (2020). Opposite effect of ablation on early/late-phase thromboembolic incidence in patients with atrial fibrillation: A meta-analysis on more than 100,000 individuals. Clinical Cardiology, 43(6), 594–605.

Macaskill, P., Walter, S. D., & Irwig, L. (2010). A comparison of methods to detect publication bias in meta-analysis. Statistics in Medicine, 20(4), 641–654.

Marron, T. R., & Faust, M. (2018). Free association, divergent thinking, and creativity: Cognitive and neural perspectives. In R. E. Jung & O. Vartanian (Eds.), The Cambridge Handbook of the Neuroscience of Creativity (pp. 261–280). Cambridge University Press.

Marron, T. R., Lerner, Y., Berant, E., Kinreich, S., Shapira-Lichter, I., Hendler, T., & Faust, M. (2018). Chain free association, creativity, and the default mode network. Neuropsychologia, 118, 40–58.

Mednick, S. A. (1968). The remote associates test. The Journal of Creative Behavior, 2(3), 213–214.

Mednick, S. A. (1962). The associative basis of the creative process. Psychological Review, 69(3), 220–232.

Murray, S., Liang, N., Brosowsky, N., & Seli, P. (2021). What are the benefits of mind wandering to creativity? Psychology of Aesthetics, Creativity, and the Arts. Advance online publication.

Nikolakopoulou, A., Mavridis, D., & Salanti, G. (2014). How to interpret meta-analysis models: Fixed effect and random effects meta-analyses. Evidence-Based Mental Health, 17(2), 64.

Orwig, W., Diez, I., Vannini, P., Beaty, R., & Sepulcre, J. (2021). Creative connections: Computational semantic distance captures individual creativity and resting-state functional connectivity. Journal of Cognitive Neuroscience, 33(3), 499–509.

Orwin, R. G., & Vevea, J. L. (1994). Evaluating coding decisions. In H. Cooper & L. V. Hedges (Eds.), The Handbook of Research Synthesis and Meta-Analysis (pp. 177–203). New York, NY: Russell Sage Foundation.

Paulsen, J. S., Romero, R., Chan, A., Davis, A. V., Heaton, R. K., & Jeste, D. V. (1996). Impairment of the semantic network in schizophrenia. Psychiatry Research, 63(2), 109–121.

Plucker, J. A., & Makel, M. C. (2010). Assessment of creativity. In J. C. Kaufman & R. J. Sternberg (Eds.), The Cambridge Handbook of Creativity (pp. 48–73). Cambridge University Press.

Prabhakaran, R., Green, A. E., & Gray, J. R. (2013). Thin slices of creativity: Using single-word utterances to assess creative cognition. Behavior Research Methods, 46(3), 641–659.

Ralph, M. A. L., Jefferies, E., Patterson, K., & Rogers, T. T. (2017). The neural and computational bases of semantic cognition. Nature Reviews Neuroscience, 18(1), 42–55.

Reiter-Palmon, R., Forthmann, B., & Barbot, B. (2019). Scoring divergent thinking tests: A review and systematic framework. Psychology of Aesthetics, Creativity, and the Arts, 13(2), 144–152.

Rosenthal, R., & Robert, M. (1979). The file drawer problem and tolerance for null results. Psychological Bulletin, 86(3), 638–641.

Rossmann, E., & Fink, A. (2010). Do creative people use shorter associative pathways? Personality and Individual Differences, 49(8), 891–895.

Rothenberg, A. (1973). Word association and creativity. Psychological Reports, 33(1), 3–12.

Runco, M. A. (2002). Creativity. In V. S. Ramachandran (Ed.), Encyclopedia of the Human Brain (pp. 83–87). Salt Lake City, UT: Academic Press.

Runco, M. A., Abdulla, A. M., Paek, S. H., Al-Jasim, F. A., & Alsuwaidi, H. N. (2016). Which test of divergent thinking is best? Creativity. Theories–Research-Applications, 3(1), 4–18.

Runco, M. A., Pritzker, S. R., & Reiter-Palmon, R. (1999). Encyclopedia of Creativity. Salt Lake City, UT: Academic Press.

Ruth, J. E., & Birren, J. E. (1985). Creativity in adulthood and old age: Relations to intelligence, sex and mode of testing. International Journal of Behavioral Development, 8(1), 99–109.

Schilling, M. A. (2005). A "small-world" network model of cognitive insight. Creativity Research Journal, 17(2–3), 131–154.

Shimonaka, Y., & Nakazato, K. (2007). Creativity and factors affecting creative ability in adulthood and old age. Japanese Journal of Educational Psychology, 55(2), 231–243.

Siew, C. S. Q., Wulff, D. U., Beckage, N. M., & Kenett, Y. N. (2019). Cognitive network science: A review of research on cognition through the lens of network representations, processes, and dynamics. Complexity, 2019, 2108423.

Silvia, P. J., Beaty, R. E., & Nusbaum, E. C. (2013). Verbal fluency and creativity: General and specific contributions of broad retrieval ability (Gr) factors to divergent thinking. Intelligence, 41(5), 328–340.

Silvia, P. J. (2015). Intelligence and creativity are pretty similar after all. Educational Psychology Review, 27(4), 599–606.

Silvia, P. J., Winterstein, B. P., Willse, J. T., Barona, C. M., Cram, J. T., Hess, K. I., Martinez, J. L., & Richard, C. A. (2008). Assessing creativity with divergent thinking tasks: Exploring the reliability and validity of new subjective scoring methods. Psychology of Aesthetics, Creativity, and the Arts, 2(2), 68–85.

Simon, R., & Bock, O. (2016). Influence of divergent and convergent thinking on visuomotor adaptation in young and older adults. Human Movement Science, 46, 23–29.

Sun, J.-R., Kong, C.-F., Qu, X.-K., Deng, C., Lou, Y.-N., & Jia, L.-Q. (2020). Efficacy and safety of probiotics in irritable bowel syndrome: A systematic review and meta-analysis. Saudi Journal of Gastroenterology, 26(2), 66–77.

Tempest, B., & Radel, R. (2019). Put on your (fNIRS) thinking cap: Frontopolar activation during augmented state creativity. Behavioural Brain Research, 373, 112082.

Terrin, N., Schmid, C. H., & Lau, J. (2005). In an empirical evaluation of the funnel plot, researchers could not visually identify publication bias. Journal of Clinical Epidemiology, 58(9), 894–901.

Torrance, E. P. (1965). Rewarding Creative Behavior. Denver, CO: Prentice Hall.

Torrance, E. P. (1972). Predictive validity of the Torrance tests of creative thinking. The Journal of Creative Behavior, 6(4), 236–262.

Torrance, E. P. (1988). The nature of creativity as manifest in its testing. In R. J. Sternberg (Ed.), The Nature of Creativity (pp. 43–75). Cambridge University Press.

Verhaeghen, P., & Paul, S. (2003). Aging and vocabulary scores: A meta-analysis. Psychology and Aging, 18(2), 332–339.

Viechtbauer, W. (2007). Publication bias in meta-analysis: Prevention, assessment and adjustments. Psychometrika, 72(2), 269–271.

Volle, E. (2018). Associative and controlled cognition in divergent thinking: Theoretical, experimental, neuroimaging evidence, and new directions. In R. E. Jung & O. Vartanian (Eds.), The Cambridge Handbook of the Neuroscience of Creativity (pp. 249–260). Cambridge University Press.

Wang, P., Wijnants, M. L., & Ritter, S. M. (2018). What enables novel thoughts? The temporal structure of associations and its relationship to divergent thinking. Frontiers in Psychology, 9, 1771.

Weinberger, A. B., Iyer, H., & Green, A. E. (2016). Conscious augmentation of creative state enhances "real" creativity in open-ended analogical reasoning. PLoS One, 11(3), e0150773.

Wu, C. H., Cheng, Y., Ip, H. M., & McBride-Chang, C. (2005). Age differences in creativity: Task structure and knowledge base. Creativity Research Journal, 17(4), 321–326.

Wulff, D. U., De Deyne, S., Jones, M. N., & Mata, R. (2019). New perspectives on the aging lexicon. Trends in Cognitive Sciences, 23(8), 686–698.

Zhang, Y., Li, S., & Yu, G. (2019). The relationship between self-esteem and social anxiety: A meta-analysis with Chinese students. Advances in Psychological Science, 27(6), 1005–1018.

Zhang, W., & Niu, J. (2013). Creativity in the later life: Factors associated with the creativity of the Chinese elderly. Journal of Creative Behavior, 47(1), 60–76.

Zortea, M., Menegola, B., Villavicencio, A., & de Salles, J. F. (2014). Graph analysis of semantic word association among children, adults, and the elderly. Psicologia: Reflexão e Crítica, 27(1), 19–28.

Gong, Z., Liu, C., & Wang, S. (2016). Some thoughts on creativity measurement. Advances in Psychological Science, 24(1), 31–45.

Xu, X., & Xin, T. (2013). Research orientations and new developments in creativity measurement. Tsinghua Journal of Education, 34(1), 54–63.

Zhang, Y., Li, S., & Yu, G. (2019). The relationship between self-esteem and social anxiety: A meta-analysis based on Chinese student populations. Advances in Psychological Science, 27(6), 1005–1018.

Wen, Z., & Wu, Y. (2011). Applications of common effect sizes in psychological research. Advances in Psychological Science, 19(12), 1868–1878.

Note: Figure translations are in progress. See original paper for figures.