Semantic Retrieval Strategies in Divergent Thinking

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Abstract

In this study we investigate semantic retrieval strategies in order to inform discussions about cognitive mechanisms underlying divergent thinking and creativity. Relying on a verbal fluency task, we map the particular associative strategies participants engage and how they predict their performance. The study starts from the assumption that during divergent thinking processes, participants move along a path through a semantic space, and that each step is prompted by an associative strategy taking them from one word to the next. There are, however, a number of such strategies, and we predict that the outcome of the process is contingent on participants' engagement of and shift between strategies. The study consists of a two-part elicitation paradigm where participants first conduct a verbal fluency task and then are guided through a meta-cognitive retrieval process to individuate the strategies employed in the task. We report significant correlations between the engagement of associative strategies and outcome measures of divergent thinking in terms of originality, flexibility and fluency.

Keywords: Divergent Thinking; Creativity; Cognitive Psychology; Semantic memory; Semantic network

Introduction

Although creativity is recognized to be a critical component of many practices across domains of design, research, innovation, and learning, there is still little consensus on how to define and measure it. Different influential theories of creativity thus focus on quite different aspects of the creative process. While some emphasize the role of motivation (Amabile, 1983), others address evolutionary aspects (Campell, 1960), neurophysiological underpinnings (Dietrich, 2019), socio-cultural influences (Sawyer, 2011), the ability to associate concepts (Mednick, 1962), the ability to explore possible solutions through the process of divergent thinking (Guilford, 1968), or the interplay of a variety of skills (Gardner, 1995).

While acknowledging this breadth of important aspects of what it means to be creative, here we will focus on the way people access and explore semantic spaces to produce multiple candidate responses to a prompt. In other words, following the lead of, for instance, Guilford (1968) and Mednick (1962), we investigate ideation processes expressed through language.

The term *divergent thinking* (Guilford, 1968) refers to the process of spontaneous generation of ideas. It is often contrasted with *convergent thinking* which describes processes of logical reasoning, and decision making aiming at identifying a single, optimal solution to a problem. Both convergent and divergent thinking are considered to be part of a creative process, but in different phases (Dietrich, 2004). In the ideation phase, which is the topic of this study, divergent thinking is considered the key process. Related to the processes of divergent thinking, the *Theory of Associative Thinking* (Mednick, 1962), focuses on how associative connections between the components of a novel idea are established. These were initially believed to be unconscious (Bowden et al., 2005, Kounios et al., 2006). However, more recent studies suggest that associations can also be governed by executive functions related to retrieval abilities and subject to controlled attention (Beaty & Silvia, 2012; Benedek et al., 2014). In other words, the ability to create novel ideas seems to arise from an interplay between executive and associative abilities (Beaty et al. 2014).

The Verbal Fluency Task as a tool to measure creativity

Due to the complex nature of creativity, it is inherently difficult to operationalize and measure. The most commonly used psychometric measures applied to creativity are, however, tests of divergent thinking (e.g. Beaty et al., 2020; Runco & Acar, 2020; Rocca & Tylén, 2022). There are various batteries of such tests (Guilford, 1968; Wallach & Kogan, 1965; Urban & Jellen, 1986, Torrance 1966). The Torrance Tests for Creative Thinking (TTCT) remains one of the most popular. In this battery, participants perform both verbal and non-verbal tasks, proposing, for instance, unusual use for ordinary items. Participants' responses are scored in terms of their relative originality, flexibility, fluency, and elaboration.

Initially the verbal fluency task (henceforth VFT) was not associated with divergent thinking, but used for the

In M. Goldwater, F. K. Anggoro, B. K. Hayes, & D. C. Ong (Eds.), *Proceedings of the 45th Annual Conference of the Cognitive Science Society.*

assessment of verbal functioning in clinical research. However, the relation between creativity and word fluency was recognized, for instance, by Carroll (1993) and has recently been adopted as a measurement of divergent thinking and creative association (Beaty et al., 2014). During the VFT, participants are asked to spontaneously list as many items as they can from a domain specified by the experimenter (e.g., "animals" or "vegetables"). The scoring system developed for TTCT can be easily applied to these responses, and the test presents decent correlations with the traditional tests (Beaty & Johnson 2021). An additional advantage of this method is that, contrary to the manual annotation and scoring of the traditional TTCT, responses from a VFT can be automatically computed with respect to their relative semantic distances relying on large language models, which facilitate scaling of the studies to include large sample sizes and help avoid coder bias.

The spatial interpretation of semantic associations

In studies of cognitive search, problem-solving and semantic retrieval, we often rely on spatial metaphors. Different solutions are thought to be nodes in spatial networks grouped together into clusters and then further into subclusters (Newell & Simon, 1972). In this context, searching for a solution means to move through the solution space, by jumping from one node to the next (Hart et al., 2017). In some operationalizations, the distance between nodes can be quantified, for instance, based on reaction time, association strength, or the relative difference between nodes. With analogies to the dynamics of foraging behavior, this makes it possible to characterize an individual's search process with respect to phases of exploration (when making long jumps between distal nodes of the network) or exploitation (when moving between neighboring nodes in space, Baronchelli & Radicchi, 2013; Hills et al., 2015).

In a recent agent-based simulation study, Rocca & Tylén (2022) applied the idea of cognitive search as movement in a solution space in the context of a VFT. Here movements between words are thought to be governed by the relative association strength between words, which can vary as a function of individual differences in the semantic spaces themselves or the search strategies that individuals engage. Likewise, this study will focus on the search process itself rather than only the outcome of the VFT (e.g., in terms of fluency). In particular, we are interested in mapping the repertoire of strategies by which individuals navigate their semantic spaces. Following Newell et al., (1962), by strategy, we understand any principle that motivates the selection of search criteria. We will attempt to classify the different types of associations that can bring an individual from one word to the next. An association from 'dog' to 'duck' can for instance be driven by semantic associations related to household animals, by the fact that these animals show up as characters in the same Disney cartoons, or by similarities in phonetic qualities of the words. This study is guided by the prediction that the repertoire of strategies - and the ability to flexibly shift between them - is predictive of outcome in the context of divergent thinking.

According to the controlled-attention theory of creativity (Beaty & Silvia, 2012), the process of generating ideas, or in this case, responses to the VFT, can, at least to some extent, be made subject of meta-cognitive introspection. Thus, we build on the assumption that participants can reliably report on their associative strategies when these are elicited in the context of a post-task interview (Jack & Roepstorff 2003).

Present study

In the present study we map and classify the associative strategies engaged by participants and investigate whether these are correlated with different metrics of performance in the VFT. Prior to this study some researchers (Gilhooly et al., 2007) have already made attempts at identifying relations between selected strategies and DT scores, but such relations are largely unexplored and more research is warranted on the mechanisms behind creative ideation.

The study, conducted in Polish, follows a two step approach where participants were first prompted to perform a VFT, and then subsequently invited to revisit their retrieval process by introspecting about how they made each individual transition between words provided in their lists.

Based on the literature reviewed in previous sections, we set out to test two hypotheses, both of which focus on contingencies between the dynamics of search processes and outcomes of the VFT. First, we hypothesize that the composition of strategies is systematically associated with performance in the VFT as operationalized by the classical divergent thinking scores, *fluency*, *flexibility* and *originality*. In particular, we predict that engaging multiple strategies will facilitate exploration of the semantic space giving rise to higher originality, fluency and flexibility.

Second, we hypothesize that the number of shifts between strategies during the VFT is systematically associated with the divergent thinking scores. In particular we predict that the number of shifts between strategies will impact the flexibility by which participants search their semantic spaces, since change of strategy can assist participants in escaping cognitive fixation and entering a new subdomain.

In summary, the first hypothesis focuses on the repertoire and composition of strategies, while the latter points towards the flexibility and dynamics by which participants engage these.

Method

Participants

Eighteen participants, 23 - 44 years old, 7 females and 11 males, were recruited through social media and advertisement at the [anonymized]. Participants were purposely recruited among students of Cognitive Science and related areas, since the study required a considerable level of self-awareness and metacognitive skills (Nelson, 1992). All the participants are native Polish speakers.

Design and Procedure

The study consisted of two parts: a verbal fluency task and an interview with the experimenter in which the participants provided reflections on their responses given in the VFT. The domain selected for the VFT was "animals", which has previously been used, for instance, by Rocca & Tylén (2022). Familiarity with various animals is considered a common knowledge, thus this task should not pose a problem for participants. To avoid biases, participants who self-reported to have professional experience in Zoology or related domains were excluded from the sample.

Before the experiment started, participants were informed about the recording procedure of both tasks. In instructions for the VFT, the purpose of the second task was not revealed - it was only mentioned that there would be an interview session with the experimenter. After the interview, participants were debriefed about the purpose of the second part of the study and how the data would be analyzed.

Participants first performed a VFT. They were instructed to orally list as many animals as they could think of within 3 minutes while being recorded on a Macbook laptop. During the VFT, the experimenter recorded a timestamp for each consecutive word by clicking a button. Animal names not audible due to technical reasons were excluded from analysis. Repetitions of the same animal by a participant were also excluded (less than 3% of responses overall). After completion of the VTF, participants were invited to listen to the recording of their own voice, word by word. After hearing two consecutive animals, the participants were presented with the question „why do you think you mentioned this animal after the previous one?". Participants' responses were recorded and written down by the experimenter. There was no time limit on the interview part of the task. Both parts of the study took place in a quiet environment, without distractions. The duration of a full session was approximately 30-45 min.

Operationalizing Variables

The data collected for analysis consisted of participants' responses to the VFT and their introspections provided during the interview shortly after the VFT. Participants' introspections from the interview were annotated and grouped by the specific strategies by which they moved through semantic space.

In response to the first hypothesis, we operationalize a participant's *composition of strategies* as the entropy of listed associative strategies. For each participant, the probability of using a strategy is calculated based on the number of times it was used in the VFT, as compared to the total of responses. From here, the value of entropy is obtained following Shannon's Entropy formula, as the negative sum of the probabilities multiplied by the logarithm of probabilities (Shannon, 1948). In this context, high entropy corresponds to a situation where multiple strategies are used to a more-or-less equal degree, while low entropy corresponds to a situation where there is a differential engagement of different strategies.

To test the second hypothesis, we counted the number of times a participant shifted between strategies (irrespective of whether these included many or few), that is, the instances in which a participant applied a strategy different to the one used to access the previous animal in the list.

In operationalization of the outcome variables, the words listed in the VFT were analyzed in terms of Torrance's (1966) divergent thinking scores, consisting of flexibility, originality and fluency. Fluency is calculated by counting the number of words listed within the 3 minutes of the test. A summary originality score per participant is calculated by obtaining the frequency of each word mentioned by a subject, based on the whole corpus of responses across participants, inverting it and averaging the originality scores of all words listed by a participant. Flexibility is by far the most complex score. It is obtained by calculating the semantic distance between each two consecutive words within a semantic space. As a model of the semantic space we take Sentence Transformers (Reimers & Gurevych, 2019) pre-trained language model for Polish „paraphrase-multilingual-MiniLM-L12-v2". Following Hills et al. (2015), semantic distances are divided into phases of exploration and exploitation. Exploitative moves are shorter and considered an expression of staying in a local region of semantic space to exhaust a cluster of items. Exploratory moves are longer and allow participants to exit their current cluster to enter a new one, and are often associated with cognitive flexibility (Rosenberg et al., 2022).

In order to annotate moves between consecutive animals from participants' lists, we relied on k-means clustering applied to the pairwise semantic distances of all combinations of animals. Flexibility is thus calculated as the ratio of explorative moves over all moves made by a participant.

Tools

The experiment was conducted using a custom python script created with the scipy library run on a standard windows laptop. It recorded participants' audio responses and the experimenters' keyboard presses which divided the audio into chunks to facilitate the subsequent interview phase. Here, the experimenter played back individual pairs of responses to elicit the participants' introspections. Responses to the second part of the study were recorded using a mobile phone.

Pilot study

The experiment was preceded by a pilot study that included 3 participants. Two of them were interviewed in their own household and one through an on-line video conference. The pilot confirmed the intuition that participants in the majority of cases are able to retrieve the reasoning behind their associations. As a result of these trials it was concluded that the duration of VFT should be 3min to allow participants to exhaust their knowledge in the domain of animals. From a

technical point of view, the pilot study discredited on-line video call as a viable option for interviewing participants due to the difficulties recording audio through microphones and speakers generally available in the households.

Preprocessing of the data

Recordings of participants' responses from both parts of the experiment were transcribed and translated to English to facilitate collaboration in the international research team.

First, a set of seven recurrent strategies were identified across participants' introspective reports. These were the following: *Taxonomy, Feature Extraction, Cultural, Formal, Imagery, Episodic, and Metacognitive strategies*.

Taxonomy This is the strategy of associating animals based on their biological relation, for instance naming various species from one genera or listing breeds.

Feature Extraction This is another broad strategy of associating animals based on shared features such as, for instance, being poisonous, moving in a similar fashion, sharing similar locations, etc.

Cultural The cultural strategy includes associations rooted in arts and culture. Examples include animals appearing in the same movie, book or cartoon, or animals associated through traditions in a given country.

Formal the formal strategy covers associations based on features of the words themselves, for instance words starting with the same letter, rhyming, or having similar phonetics (Connell, 2019).

Imagery This strategy incorporates associations based on mental imagery. When a person appeared to base their associations on a detailed description of a particular scene it was classified as *imagery* (Mednick, 1962).

Episodic The episodic strategy is based on personal memories and associations specific to an individual, for instance, a recent visit to the zoo, one's childhood pets etc. (De Brigard et al, 2022 ,Vatansever et al, 2021, Binder et al., 2009, Irish, 2020; Lane et al., 2015).

Metacognitive This last strategy incorporates the associations that were made through an explicit and deliberate shift of attention towards a different subdomain. When a participant reflected on the need to make a change in the currently applied strategy, it was considered a meta-strategy.

Occasionally, there were responses for which participants were not able to provide an explanation. These were coded as "*not aware*".

Having established the coding scheme of different strategies, individual responses from the interviews were annotated by the first author by assigning a strategy to each two consecutive words in a list.

Hypotheses were tested relying on a general linear model regression approach. Analyses which had a count variable as outcome, were modeled as a Poisson distribution, while models with a continuous outcome were modeled as a regular Gaussian distribution. All the statistical analyses were carried out relying on the *statsmodels.api package* for Python.

Results

With respect to the first hypothesis, we observe a significant association between *entropy of strategies* and *flexibility*, β = -0.31, SE = 0.10, t = -2.97, $p < .01$, R^2 = 0.35 (see figure 1a). Likewise, we found an effect of *entropy of strategies* and *originality*, β = 0.01, SE = 0.004, t = 2.83, p = .012, R^2 = 0.33 (see Table 1 and figure 1b). The correlation between entropy and fluency was not significant (p = .09, see Table 2 and Figure 2).

Table 1: Linear Regression results between entropy and the scores of flexibility and originality

	COEFF	SE	T-score	p-value	R^2
Entropy~ Flexibility	-0.3092	0.104	-2.975	0.009	0.356
Entropy~ Originality	0.0107	0.004	2.833	0.012	0.334

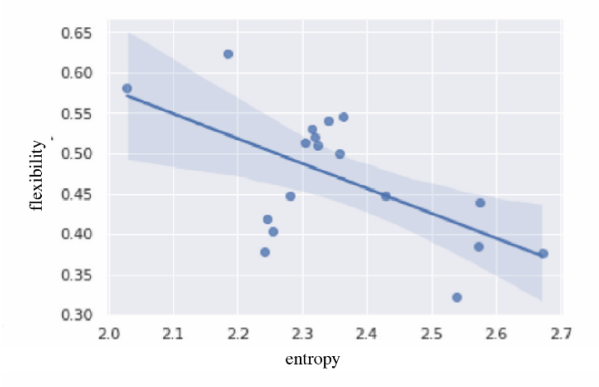

Figure 1a: Scatter plot of data and linear regression model fit between entropy and flexibility score.

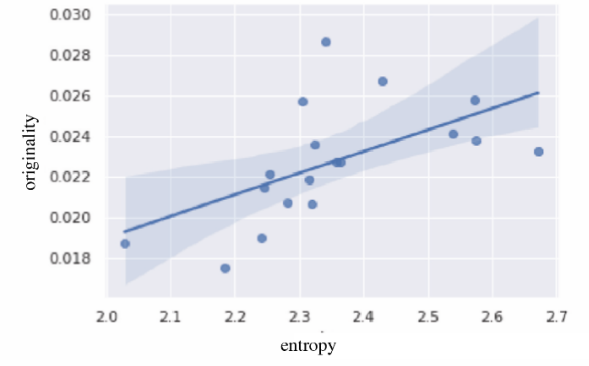

Figure 1b: Scatter plot of data and linear regression model fit between entropy and originality score.

Table 2: Poisson Regression results between entropy and fluency

	COEFF	SE	Z-score	p-value	chi^2
Entropy~ Fluency	-0.3547	0.214	-1.657	0.098	39.7

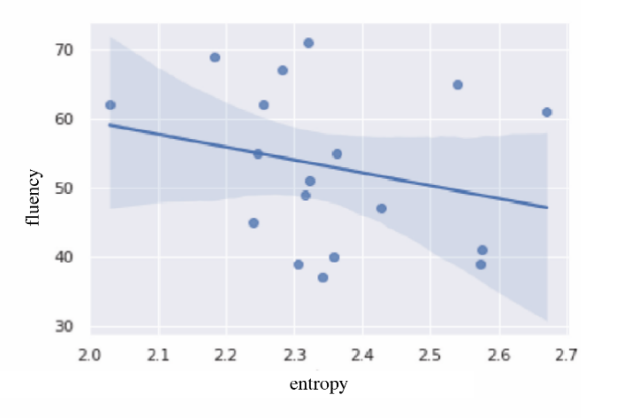

Figure 2: Scatter plot of data and poisson regression model fit between entropy and fluency score.

With respect to the second hypothesis, that the number of strategy changes predict divergent thinking scores, we observe a significant relation between *strategy changes* and *fluency*, β = -0.93, *SE* = 0.46, *z* = -2.03, p < .05 (see Table 4 and Figure 4). The relation between strategy changes and flexibility and originality was not significant (p = .966 and 0.165 respectively, see Table 3 and figure 3a and b).

Table 3: Linear Regression results between number of changes of the strategies and the scores of flexibility and originality

	COEFF	SE	T-score	p-value	R^2
Change~ Flexibility	-0.0123	0.280	-0.044	0.966	0.000
Change~ Originality	0.0136	0.009	1.465	0.165	0.117

Table 4: Poisson Regression results between number of strategy changes and the score of fluency

	COEFF	SE	Z-score	p-value	chi^2
Change~ Fluency	-0.9308	0.457	-2.035	0.042	38.6

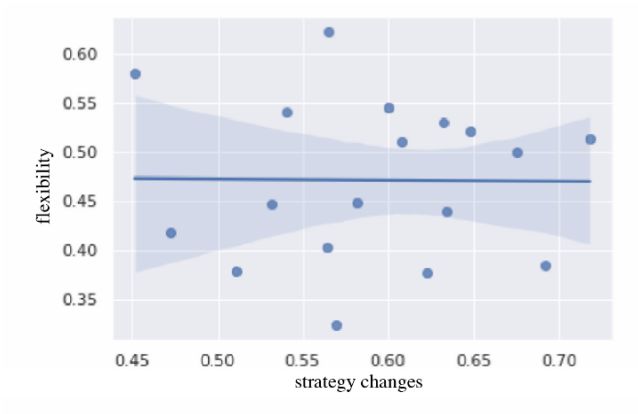

Figure 3a: Scatter plot of data and linear regression model fit between number of strategy changes and flexibility score.

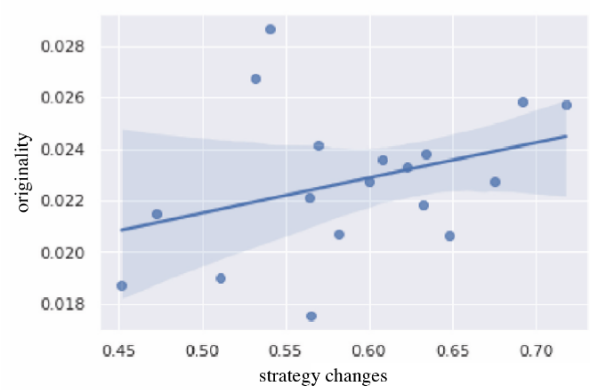

Figure 3b: Scatter plot of data and linear regression model fit between number of strategy changes and originality score.

Figure 4: Scatter plot of data and poisson regression model fit between number of strategy changes and fluency score.

Discussion

In a elicitation study, we set out to investigate the relationship between cognitive search strategies and the outcomes of a divergent thinking process. The observed effects supported our predictions only with regard to the relation between entropy of strategies and the originality of listed animals.

First, a significant negative relation is observed between the entropy of strategies and the flexibility by which participants navigate their semantic spaces. That is, contrary to our predictions, diversification of strategies does not necessarily mean diversity of the subdomains within a topic. One might apply multiple strategies and still remain only within a narrow range of the network, or apply a single strategy and travel longer semantic distances and explore larger areas (e.g., applying the *formal* strategy - that is associating animals by similarity of their word sounds - appears to facilitate long jumps in semantic space). This is an important observation to understand which aspects of creative exploration of semantic space can be grasped by the VFT and DT scores and which would require additional measures.

Second, in support of our predictions, we observe a systematic positive relation between entropy and originality, suggesting that the use of multiple strategies accommodate the participant to access more remote areas of the semantic space.

In regard to the second hypothesis, we observe a significant negative relation between the number of shifts and fluency, that is, the number of animals listed. This suggests that participants who stayed longer with a single strategy, rather than shifting frequently between multiple strategies were more successful in multiplying their responses. Again, this went contrary to our predictions, since we expected that shifts in strategies would result in more thorough exploration of semantic space and, as a consequence, more animals. The opposite result points to another factor, namely speed of responding. It is quite possible that different strategies vary in terms of their speed of processing. Some strategies are associated with sensorimotor simulations (for instance, *imagery*) while others rely on taught knowledge of a more linguistic nature (for instance, *taxonomy*). In terms of response times, frequent shifts between such strategies might result in fewer responses within the designated time frame due to a slowing down. This is in line with claims by Connell (2018), who suggests that accessing labels is faster than relying on sensorimotor simulations. Since in the current study we also recorded response times, this assumption might be subject of future analyses. It is also possible to repeat the study with more time allocated to VFT (currently 3min) and check if the direction of effects remains the same.

The obtained results show that divergent thinking scores might - at least partially - depend on semantic retrieval strategies.

Limitations

There are several aspects that might affect the accuracy of the results, which are listed below.

Response bias The reliability of casual participants' introspective abilities has often been questioned. There is a possibility that the associative strategies provided by participants during the interviews are a product of post-factum rationalization and not reliably related to actual associations made in the moment of answering. In other words, we do not have access to participants' metacognitive abilities (Nelson, 1992). Many participants expressed awareness of such possibility, and whenever remarks were made of uncertainty or post hoc speculation, we labeled the data point as „*not aware*".

Generalization issues The scope of the study is limited both in terms of population and linguistic domain. Further studies need to be done that include both a larger population from more diverse backgrounds and more varied domains in which the associations are performed.

Technical limitations The semantic distances applied in the operationalization of the flexibility scores are based on currently available pre-trained distributional semantic models for the Polish language. With fast advances in the area of natural language processing, more advanced computational language models could soon become available yielding more precise operationalizations of this variable.

Conclusion

In the presented study, we show that it is possible to identify and classify semantic retrieval strategies that people use during ideation. Moreover, the study suggests that these strategies, observed in trajectories of movement through semantic space during a verbal fluency task, are to some extent related to aspects of divergent thinking and creative potential. The current study aligns with many ongoing investigations addressing the role of executive and associative abilities in creative processes. The manner in which the information about those strategies was obtained - through a combination of a verbal fluency task and introspective interviews with participants, is novel and shows a potential to be further explored.

The prospects of establishing connections between semantic retrieval strategies and creativity is promising and the results presented in this study are encouraging for the elaboration of future studies. A first step would be a follow-up with a larger sample size to ensure better statistical sensitivity, which might reveal more details in the interdependence of each strategy and aspects of divergent thinking.

Acknowledgments

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 952324

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