Title
Do constraints in APM solving affect APM-like puzzle creation?

Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 45(45)

Authors
Arcot, Nishanth
Srivastava, Priyanka
Jaarsveld, Saskia, Phd, Dr habil.

Publication Date
2023

Peer reviewed

Do constraints in APM solving affect APM-like puzzle creation?

Nishanth Arcot (nishanth.arcot@research.iiit.ac.in)
Perception and Cognition Lab, Cognitive Science Centre, International Institute of Information Technology
Hyderabad (IIITH), Hyderabad, Telangana, India

Priyanka Srivastava (priyanka.srivastava@iiit.ac.in)
Perception and Cognition Lab, Cognitive Science Centre, International Institute of Information Technology
Hyderabad (IIITH), Hyderabad, Telangana, India

Saskia Jaarsveld (jaarsvel@rhrk.uni-kl.de)
Department of Social Sciences, Technische Universität Kaiserslautern, Kaiserslautern, Reinland Pfalz, Germany

Abstract

The current study examines the role of constraints in well-defined problem-solving in ill-defined problem-solving. We chose variants of Raven's advanced progressive matrices(APM) for well-defined problem-solving and creative reasoning tasks (CRT) for ill-defined problem-solving. Using traditional APM, we created a novel version of APM with comparatively lesser constraints available to solve the puzzle, called creative APM(cAPM). The cAPM task was designed to induce divergent thinking along with convergent thinking. It is assumed that the difference in constraints changes the nature of the problem space in solving APM and cAPM and may differently affect the following creative reasoning task. We randomly assigned 50 participants to perform APM or cAPM, followed by the CRT, in a fixed order. We observed a significant effect of constraints available to solve well-defined problems on ill-defined problem-solving. The current result showed higher CRT scores when CRT preceded cAPM (*Median* = 79.25) than APM (*Median* = 53.00). The result suggests that the flexibility in constraints to solve a well-defined problem induces more divergent thinking alongside convergent thinking and facilitates creative thinking required in ill-defined problem-solving.

Keywords: Raven's Advanced Progressive Matrices (APM); Creative Reasoning Task (CRT); Standardized APM; creative APM (cAPM); Convergent Thinking; Divergent Thinking; Cognitive Strategies

Introduction

People encounter various kinds of problems in their day-to-day lives. Some are very open-ended and don't have a definite correct solution. For instance, choosing a dress for a party, a location to visit for the next holiday, or a research problem to work on, to name a few. Such problems are called ill-defined problems. The correctness and acceptance of the solutions depend not only on the problem but on the individuals, social and historical circumstances (Boden, 1990; Strohschneider & Güss, 1998). Kitchener (1983) states that well-defined problems have solutions that are absolutely correct and have a certain guaranteed way of reaching the answer, in contrast, ill-defined problems can have many solutions or none, where the procedural assurance for attaining a solution is not guaranteed.

Flexibility in constraints and varying degrees of freedom in using rules while defining the problem's goal and methods to achieve the solution in an ill-defined problem space allows novel and creative solutions. Such problem-solving is called creative problem-solving, an aspect of creativity in which ill-defined and ambiguous problems tend to allow creative solutions (Dillon, 1982; Getzels, 1975). Creativity has been defined in terms of the production of a "novel product, idea or problem solution that is of value to the individual and/or the larger social group" (Hennessey, 2010; Moneta, Amabile, Schatzel, & Kramer, 2010) and involves two modes of thinking, namely, convergent and divergent thinking (Brophy, 2001; Guilford, 1973; Mihaly, 2013; Jaarsveld et al., 2015; Jaarsveld & Lachmann, 2017)

During an ill-defined problem solving, divergent thinking is required at the problem's definition, identification, and goal definition stages. However, evaluating and selecting the methods/rules from the knowledge/memory to complete the problem requires convergent thinking. Jaarsveld and van Leeuwen (2005) considered convergent thinking in a design process to relate to the (re-) definition of constraints, the evaluation of sub products and the monitoring of progress, while divergent thinking was considered as the creation of new design ideas and the exploration of different compositions. These authors showed that the better designs were the outcomes of creative processes in which i) a relation was observed between the end product and the continuity of the process ii) higher-scoring participants had a better understanding of how close their design had come to its final stage and iii) these participants were more able to give a reliable estimate of their progress.

These observations show that i) training for a better intermingling/cooperation of convergent thinking and divergent thinking abilities could produce better creative solutions to ill-defined problems and ii) less constrained problem definitions lead to more creative problem solutions. Basadur, Graen, and Green (1982) reported that training involving synchronization of convergent and divergent thinking in problem construction, idea generation and idea evaluation improves creative problem-solving (Mumford, Mobley, Reiter-Palmon, Uhlman, & Doares, 1991; Basadur, Wakabayashi, & Graen, 1990). Brophy (2001) argued that divergent and convergent thinking complement each other which results in creative outcomes. Despite their importance in everyday problem-solving, only a few studies have examined the role of inducing divergent and convergent thinking in ill-defined problem-solving (Jaarsveld & van Leeuwen, 2005; Jaarsveld et al., 2015; Eymann, Beck, Jaarsveld, Lachmann, & Czernochowski, 2022).

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

Majorly, convergent and divergent thinking has been studied separately (Jaarsveld, Lachmann, & Van Leeuwen, 2012) in the form of intelligence tests (e.g., WAISR-V) (Lee, Huggins, & Therriault, 2014) and creativity tests (e.g., Guilford's alternate uses task) (Wilson, Guilford, & Christensen, 1953), which restricts us to realize the underlying cognitive processes while approaching well-versus-ill-defined problems. It also creates a friction in realizing the transfer of knowledge from solving well-to-ill-defined problem and vice-versa.

The current study aims to investigate the role of convergent and divergent thinking in creative problem-solving task performance by varying the constraints in traditional problem-solving task, using APM. We developed a novel variant of APM, called cAPM, to induce both convergent and divergent thinking in the given test. The creative APM uses the standardized APM, with comparatively lesser constraints available to approach the problem. The cAPM task description is elaborated under the method section. We used the creative reasoning task (CRT) to reduce the variability in the knowledge domain and effectively map the common features while approaching the two problems (Jaarsveld et al., 2017). It was assumed that if intermingling of convergent and divergent thinking induces creative thinking, then a better CRT score is expected when CRT is preceeded by cAPM than the traditional APM. We analyzed accuracy for solving APM and cAPM puzzles. For CRT performance, we analyzed the count and scores of rule components used in creating APM-like puzzle in CRT.

Method

Participants

A total of fifty university students (male=49, female=1, others=0, with mean age = 20.60 years, SD = 2.77) volunteered to participate in the study. A participant's data was excluded from cAPM because they showed less than three correct responses according to our scoring criteria, described below under results section. So the final analysis consisted of 49 participants (25 APM, 24 cAPM).

Material and Design

We selected only six out of the original thirty six APM puzzles for this study. The six puzzles consisted of three pure visuo-spatial and three pure verbal-analytical from Raven's APM. The selection was based on previous research to reduce the variability in representation involved in solving APM puzzles (Chen, De Beuckelaer, Wang, & Liu, 2017) and might influence traditional and cAPM solving and further CRT performance. The same puzzles were used for both the problem-solving conditions. The description of each test is given below:

APM Puzzles The Raven's advanced progressive matrices (APM) is widely used to measure non-verbal abstract reasoning pertaining to fluid intelligence. The APM puzzles consist of 2 sets. Set I contains 12 puzzles and Set II contains 36 puzzles. For the current study, we selected three visuo-spatial and three verbal-analytical APM puzzles from the set II to reduce the variability of any kind. The three visuo-spatial puzzles comprises 3, 9 and 22 puzzles and three verbal-analytical puzzles comprises 4, 8 and 13 puzzles. The order of the presentation was kept identical to the standard APM puzzle Set II. Each puzzle consisted of a 3 x 3 matrix area with 8 alternative response options, presented below the puzzle. Participants were asked to select the correct response as per their interpretation (Figure 1).

cAPM Puzzles In cAPM, the participant was provided with only either a single row or column of the same puzzle used for traditional APM in the current study. The eight alternatives in cAPM were different from traditional APM. These eight alternatives comprise six items corresponding to the original puzzle, along with two most obvious errors. Participants were instructed to deduce the rules from the partially presented puzzle, and complete the puzzle by choosing the eight alternative options presented next to the puzzle (Figure 2 and Figure 3). The participant had to click and drag the options to the puzzle grid so that it follows the APM rules. Based on the options given, the participant has to extrapolate the rules, check whether the rules work, and then in case the options do not fit, redo the puzzle. The scoring method is described below in the result section.

Creative Reasoning Task (CRT) In CRT, the participant was provided with an empty 3x3 matrix, similar to an APM puzzle, and the participant was asked to create a Raven's like matrix in a given format (Figure 4 and Figure 5) (Jaarsveld et al., 2017). They were asked to generate the complete puzzle with the answer in the last cell of the puzzle. They were not asked to generate alternatives. The scoring mechanism defined by Jaarsveld and colleagues (Please refer to the (Jaarsveld et al., 2012)) was used to evaluate the performance of CRT. For this manuscript, the CRT performance was scored using rule component and excluded the element and specification components of CRT total scores.

Design 50 participants were randomly allocated to the two independent conditions, APM and cAPM puzzle-solving, followed by the creative reasoning task (CRT). The experiment was performed in the university experimental lab. One experimenter was present in the room to clarify the doubts raised by participants if any.

Apparatus We used ReactJs and Firebase to create the website to present APM and cAPM puzzles. However, the CRT was performed using paper pencil, in which participants were asked to first draw an APM-like puzzle in an empty 3x3 puzzle box and second describe their puzzle and also give a reasoning why their puzzle is difficult to solve. The CRT sheet recorded participant ID, start time and end time.

Procedure The experiment starts with a welcome note followed by a consent form. After participants gave their consent, they were shown some general instructions followed by collection of demographic information. The participant

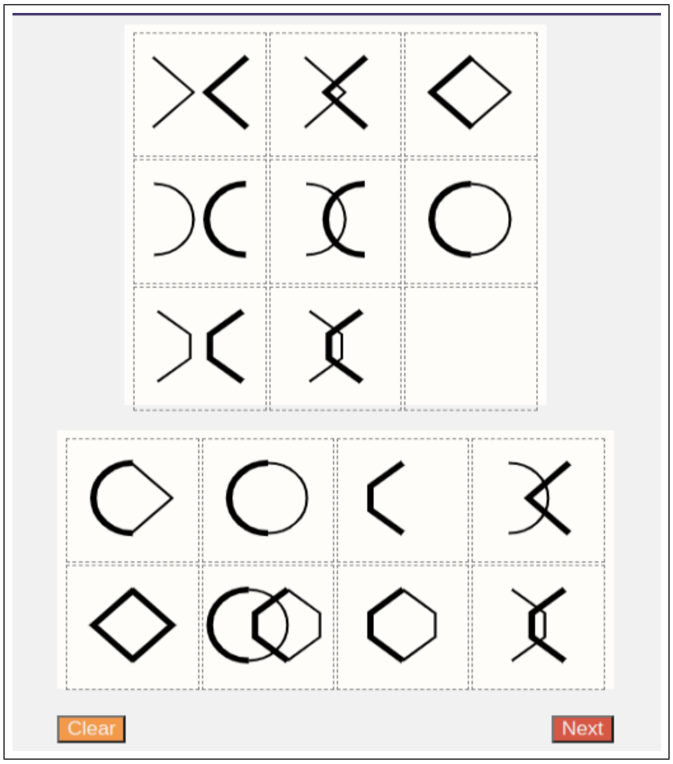

Figure 1: A sample APM puzzle with 8 alternatives. This APM puzzle image is taken from the experiment's website.

was randomly assigned to one of the two problem-solving tasks (APM and cAPM). Based on the problem-solving task, two example problems were given for a better understanding about the upcoming problem-solving task. The problem-solving task consists of six APM/cAPM puzzles. There was no time constraint for the problem-solving task. Participants were free to take their time to solve the puzzles. Once the problem-solving task finished, participants were asked to perform CRT. CRT form was handed over to them in paper along with a questionnaire to describe their CRT puzzle and why their puzzle is difficult to solve. The CRT test and the follow up questionnaire was the only part of the experiment which is performed on paper. All the remaining tasks were performed on computer using the website. The final section of the experiment was the feedback section which consisted of a NASA TLX (Hart & Staveland, 1988) and feedback about the website's UI. Participants also had the option to give additional feedback if any.

Results

The problem-solving performance for both the groups was scored using the binary scoring method. For the APM puzzle, the correct response was scored "1", and the incorrect response scored "0". For the cAPM puzzle, if all the rules present in the original APM puzzle were present in the cAPM results, then it was scored "1", otherwise "0". To be considered for statistical analysis, the cutoff was kept at 50%. This

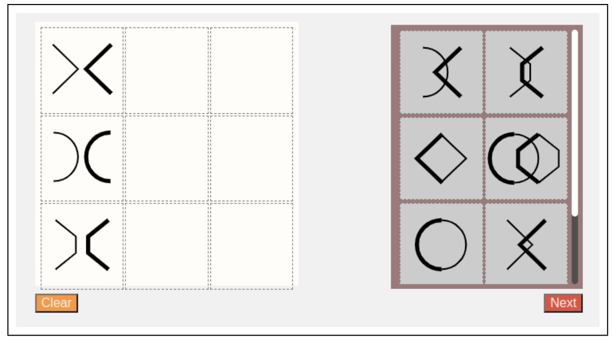

Figure 2: A sample cAPM puzzle with only one column. The left half consists of the puzzle area and the right half consists of options in the stash. This cAPM puzzle image is taken from the experiment's website.

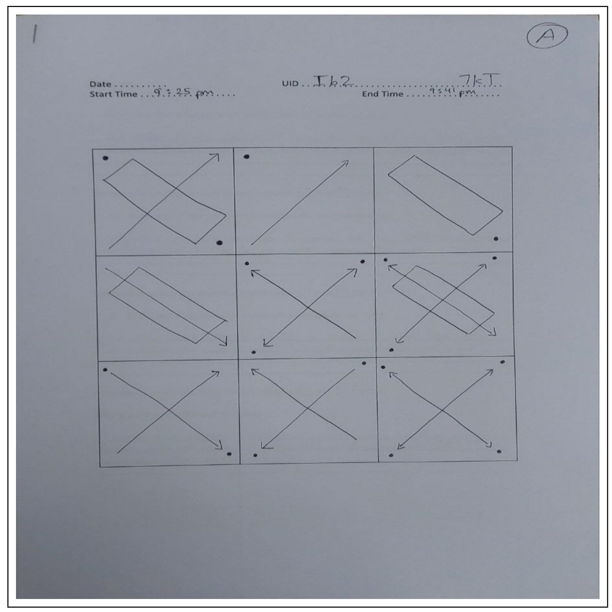

Figure 3: A sample CRT puzzle by a participant

means that participants should have solved at least 3/6 puzzles correctly under APM and cAPM conditions. The CRT performance was scored using Jaarsveld and colleagues (2012) scoring method. We analyzed only two aspects of CRT: a.the counts of rules, and b. the score to calculate the relationship between the elements.

Problem-Solving Performance (APM vs cAPM)

We observed violations of normality assumptions by using the Shapiro-Wilk test for both groups, cAPM (W = 0.89, p = 0.013) and APM (W = 0.81, $p < 0.001$). This led to choosing non-parametric analysis. Mann-Whitney U test showed a significant effect of varying constraints on well-defined problem-solving i.e, APM and cAPM on the task performance with large standardized effect size (U = 532.5, p = 0.00000146, r = 0.69). The results showed a higher accuracy

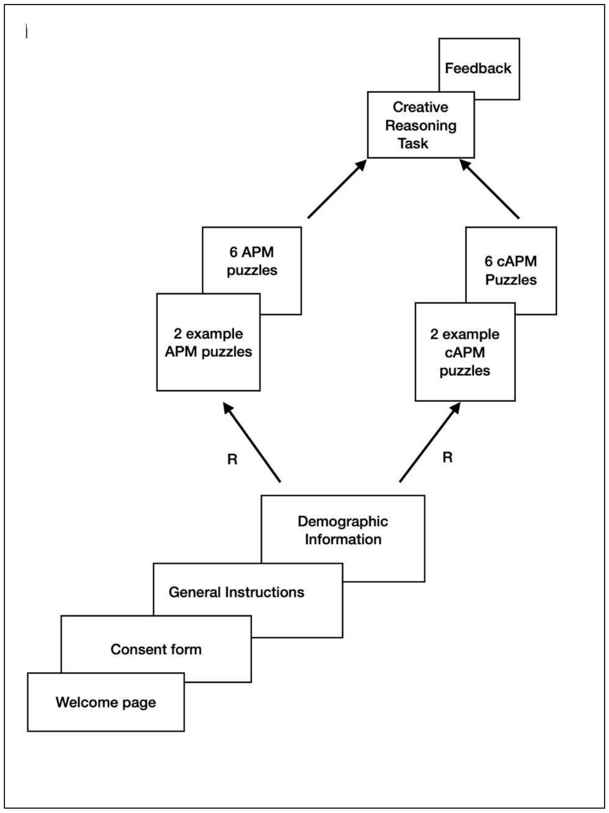

Figure 4: The schematic flow of the overall experiment. R = random assignment

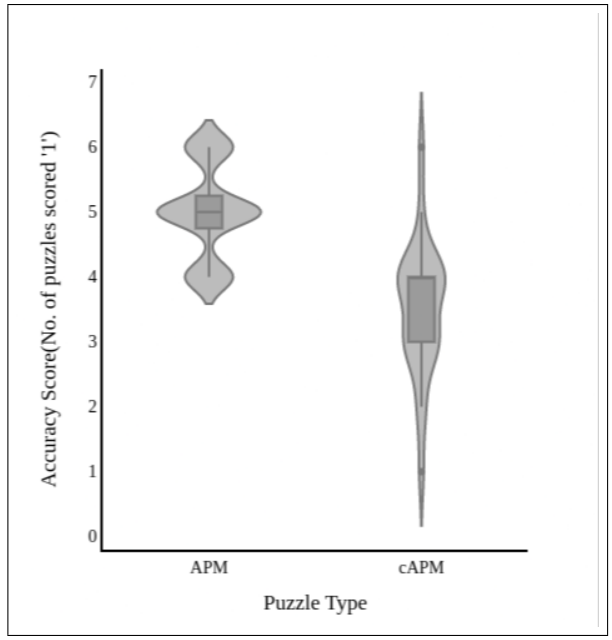

Figure 5: Accuracy scores b/w APM and cAPM

score for APM condition (*Median* = 5/6) than cAPM condition (*Median* = 4/6) (Figure 5).

CRT Performance

The CRT Performance was measured using two parameters i) Number of rules applied in CRT ii) CRT Relationship Score. Two participants from APM and two participants from cAPM group were excluded for CRT analysis because they used numbers instead of geometric and line components. This led to a total of fourty five participants for the CRT analysis. We calculated the number of rules used in the CRT, and the relationship scores by employing these rules between the geometrical and line elements.

Number of Rules in CRT The Shapiro-Wilk test for both groups indicated violation of normalcy for CRT scores, cAPM ($W = 0.88$, $p = 0.014$) and APM ($W = 0.73$, $p < 0.001$), and led us to choose non-parametric analysis. Mann-Whitney U test showed significant effect of varying constraints in APM puzzle (i.e., APM with high constraints and cAPM with lesser constraint) on the number of rules used in CRT with medium standardized effect size ($U = 125.0$, $p = 0.002$, $r = 0.46$). Participants used more number of rules in CRT when they solved APM with lesser constraints of rules, i.e., cAPM (*Median*=2) than traditional APM (*Median*=1) (Figure 6).

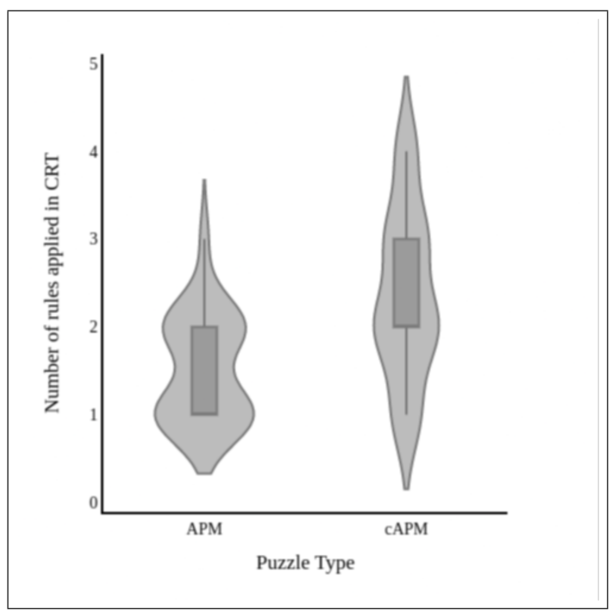

Figure 6: Number of rules applied in CRT after solving cAPM and APM

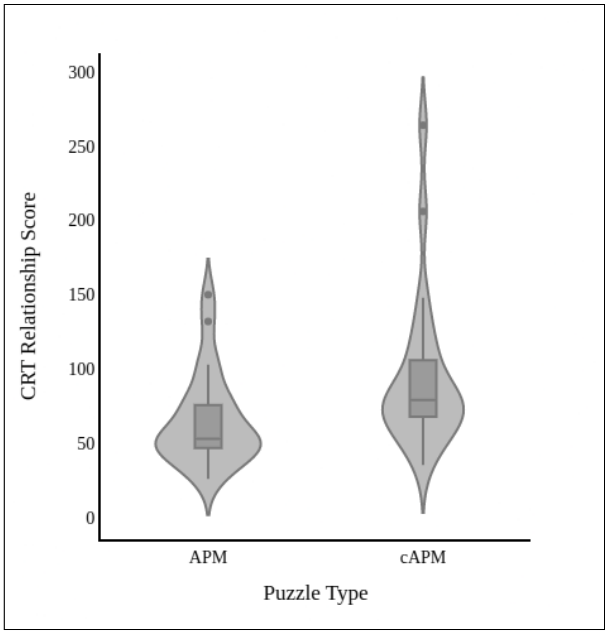

Figure 7: CRT Relationship scores after solving cAPM and APM.

CRT Relationship Score We observed a significant violation of normalcy for CRT relationship score for both groups, cAPM (W = 0.79, $p < 0.001$) and APM (W = 0.87, $p = 0.006$) and therefore performed non parametric analysis. The cAPM group showed a significantly higher CRT relationship score (*Median* = 79.25) than APM (*Median* = 53.00) with a medium standardized effect size (U = 141.5, $p = 0.011$, $r = 0.38$) (Figure 7).

Discussion

The current study examined the role of constraints in well-defined problem-solving in the ill-defined creative problem-solving task performance. The well-defined problem-solving was measured using the variant of APM (Raven, Raven, & Court, 1994), and ill-defined problem-solving was measured using CRT (Jaarsveld et al., 2017). We created a variant of traditional APM, called creative APM (cAPM), in which the rules to deduce the relationship between elements of the given puzzle were not as well-defined as in traditional APM. We assumed that cAPM, unlike traditional APM, will induce divergent thinking in well-defined problem space, as it demands creating a puzzle based on the reasoning deduced by partial information, either row or column.

In traditional APM, participants are presented with a 3x3 matrix and are allowed to exhaust all the possible rules to complete the puzzle with a single missing piece. Therefore, the correct response leads to a single answer. Whereas in cAPM the participants are presented with either a row or a column. The partial information allows more degree of freedom in the puzzle's completion. Only a row or column present to deduce the rules leads to a few alternative responses, despite a fixed number of correct answers at the end.

The cAPM completion demands searching for the rules and the elements and requires participants to create a puzzle, which may entail different cognitive processes than traditional APM. The search for rules and the constant evaluation of the relationship between the elements as the puzzle builds up demands juggling between convergent and divergent thinking. It is assumed that the search for rules in cAPM requires selective processes to filter the irrelevant features (attention and executive control function) and keeping the relevant information for future use (working memory) demands manipulation and adjustment between various options before a puzzle completion. Therefore, the processes involved in cAPM appear closer to the CRT, in which participants are asked to create an APM-like puzzle from scratch, and may facilitate CRT performance when asked to perform cAPM before CRT than traditional APM. The higher CRT score when the CRT followed the cAPM than the traditional APM is consistent with our hypothesis, suggesting that the cAPM allows participants to involve in similar cognitive processes that CRT demands and therefore shows a better CRT performance than when it follows traditional APM.

We chose APM to study well-defined problem-solving because of the shared knowledge domain with CRT. Recently, a study (Jaarsveld, et al., 2017) argued the importance of reducing the variability in intelligence and creativity tests (corresponding to well-and-ill-defined problem space) to better understand the shared and distinct cognitive processing underlying these two problem spaces. The authors (Jaarsveld et al., 2017) argue in favor of keeping the knowledge domain constant, realizing the inevitable difference between the constructs and problem spaces. The CRT was chosen because a. it shares the knowledge domain with the APM, and b., it's the only test in creative thinking that allows both convergent and divergent thinking in a single test. Previous studies (Jaarsveld et al., 2017; Eymann et al., 2022) using traditional APM and CRT have shown a strong correlation between convergent scores of CRT and traditional APM (Jaarsveld et al., 2015) and a strong correlation between divergent thinking score of CRT and widely used creative thinking task, test for creative thinking and drawing production (TCT-DP), indicating the use of divergent and convergent thinking in CRT at different stages.

Conclusion and Future Directions

It is concluded that the flexibility in constraints to solve the well-defined problem facilitates the following ill-defined problem-solving task performance. Despite encouraging behavioral data, the underlying shared cognitive mechanism and associated neural correlates demand further investigation. It is assumed that tests like APM, cAPM, and CRT will allow better examination of the well-and-ill-defined relationship in future. An interesting follow up study would be "Does flexibility in constraints to solve the well-defined problem impact ill-defined problem if both tasks are from different knowledge domain?". As an extension to this study, we can add a creativity test from different knowledge domain and check the differences in performance between the two groups.

References

Basadur, M., Graen, G. B., & Green, S. G. (1982). Training in creative problem solving: Effects on ideation and problem finding and solving in an industrial research organization. *Organizational Behavior and human performance*, *30*(1), 41–70.

Basadur, M., Wakabayashi, M., & Graen, G. B. (1990). Individual problem-solving styles and attitudes toward divergent thinking before and after training. *Creativity Research Journal*, *3*(1), 22–32.

Boden, M. (1990). The creative mind: Myths and mechanisms london: Abacus.

Brophy, D. R. (2001). Comparing the attributes, activities, and performance of divergent, convergent, and combination thinkers. *Creativity research journal*, *13*(3-4), 439–455.

Chen, Z., De Beuckelaer, A., Wang, X., & Liu, J. (2017). Distinct neural substrates of visuospatial and verbal-analytic reasoning as assessed by raven's advanced progressive matrices. *Scientific reports*, *7*(1), 16230.

Dillon, J. T. (1982). Problem finding and solving. *The journal of creative behavior*.

Eymann, V., Beck, A.-K., Jaarsveld, S., Lachmann, T., & Czernochowski, D. (2022). Alpha oscillatory evidence for shared underlying mechanisms of creativity and fluid intelligence above and beyond working memory-related activity. *Intelligence*, *91*, 101630.

Getzels, J. W. (1975). Problem-finding and the inventiveness of solutions. *The Journal of Creative Behavior*.

Guilford, J. P. (1973). Characteristics of creativity.

Hart, S. G., & Staveland, L. E. (1988). Development of nasa-tlx (task load index): Results of empirical and theoretical research. In *Advances in psychology* (Vol. 52, pp. 139–183). Elsevier.

Hennessey, B. A. (2010). The creativity—motivation connection.

Jaarsveld, S., Fink, A., Rinner, M., Schwab, D., Benedek, M., & Lachmann, T. (2015). Intelligence in creative processes: An eeg study. *Intelligence*, *49*, 171–178.

Jaarsveld, S., & Lachmann, T. (2017). Intelligence and creativity in problem solving: the importance of test features in cognition research. *Frontiers in psychology*, *8*, 134.

Jaarsveld, S., Lachmann, T., & Van Leeuwen, C. (2012). Creative reasoning across developmental levels: Convergence and divergence in problem creation. *Intelligence*, *40*(2), 172–188.

Jaarsveld, S., & van Leeuwen, C. (2005). Sketches from a design process: Creative cognition inferred from intermediate products. *Cognitive science*, *29*(1), 79–101.

Kitchener, K. (1983). Cognition, meta-cognition: A three level model of cognitive processing. *Human Development*, *26*(4), 222–232.

Lee, C. S., Huggins, A. C., & Therriault, D. J. (2014). A measure of creativity or intelligence? examining internal and external structure validity evidence of the remote associates test. *Psychology of Aesthetics, Creativity, and the Arts*, *8*(4), 446.

Mihaly, C. (2013). Creativity: The psychology of discovery and invention. *New York, Harperperennial,"Modern Classics*.

Moneta, G. B., Amabile, T. M., Schatzel, E. A., & Kramer, S. J. (2010). Multirater assessment of creative contributions to team projects in organizations. *European Journal of Work and Organizational Psychology*, *19*(2), 150–176.

Mumford, M. D., Mobley, M. I., Reiter-Palmon, R., Uhlman, C. E., & Doares, L. M. (1991). Process analytic models of creative capacities. *Creativity research journal*, *4*(2), 91–122.

Raven, J. C., Raven, J., & Court, J. (1994). *Advanced progressive matrices: Sets i & ii: Background...* Oxford Psychologists Press.

Strohschneider, S., & Güss, D. (1998). Planning and problem solving: Differences between brazilian and german students. *Journal of Cross-Cultural Psychology*, *29*(6), 695–716.

Wilson, R. C., Guilford, J. P., & Christensen, P. R. (1953). The measurement of individual differences in originality. *Psychological bulletin*, *50*(5), 362.