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Presentation Effects On Matrix Reasoning Scores

Katharine Elizabeth Lindberg

PRESENTATION EFFECTS ON MATRIX REASONING SCORES

by

Katharine E. Lindberg
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This thesis, submitted by Katharine Elizabeth Lindberg in partial fulfillment of the requirements for the Degree of Master of Arts from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

Joseph Miller, Ph.D.

Thomas Petros, Ph.D.

F. Richard Ferraro, Ph.D.

This thesis is being submitted by the appointed advisory committee as having met all of the requirements of the School of Graduate Studies at the University of North Dakota and is hereby approved.

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Katharine E. Lindberg
05/04/2017

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To my mom,
it is hard to celebrate this milestone without you, but
the strength you instilled in me and your unwavering support
enabled me to succeed. Thank you and love you.

To my family and friends,
I could not have been successful through the ups
and downs that have come my way without you all there
every step of the way.
Love you all.

ABSTRACT

Matrix reasoning tasks are popular measures of fluid and inductive reasoning ability. The impact of rule type, number of rules, grouping, overlapping elements, and unfamiliar shapes on matrix reasoning performance has been shown to make matrix tasks more difficult to solve. Alternatively, the relationship of features (the physical and visual dimensions of individual elements within a matrix) to matrix reasoning performance in an adult population has not been established. The current study aimed to test the impact of features (i.e., height, shape, width) on matrix reasoning performance in an undergraduate sample (N = 196) by systematically varying rules and features using three experimental matrix task sets. Results indicated a significant effect of feature on matrix reasoning performance ($F(2,193) = 4.871$, $p = .009$, $\eta_p^2 = .048$) when controlling for differences in inductive reasoning ability between experimental groups. Post-hoc analysis revealed significantly ($p = .007$) worse performance in the width/height feature combination as compared to the shape/height. Concluding, features have a differential impact on matrix reasoning performance, as some features may be more efficiently solved than others. Future studies using more complex scoring methods, assessment of working memory, and direct measurement of cortical functioning are warranted to clarify the impact of features on matrix reasoning performance.

CHAPTER I

INTRODUCTION

Intelligence is a complex construct, which, depending on one's theoretical perspective, can be defined differently. Typically, though, models of intelligence concern themselves with descriptions of mental processes underlying adaptive behavior generally (e.g., Goleman, 1995; Greenspan & Driscoll, 1997) and complex problem-solving more specifically (e.g., Sternberg, 1997), and/or identification of stable traits or trait-like competencies predictive of performance on specified tasks, i.e., what Sternberg (1997) described as "intelligent behavior" (e.g., Gardner, 1983; Horn & Noll, 1998). From this broad literature, three general theoretical perspectives are identified by McGrew and Flanagon (1998): the psychometric or structural theories, information processing theories, and the cognitive modifiability theories. The information processing theory of intelligence compares human processing to computer processing, in order to understand how the human brain processes information (McGrew & Flanagan, 1998). The cognitive modifiability theory assesses the dynamic nature of human intelligence, i.e., assesses how intelligence changes or is modified with new information (McGrew & Flanagan, 1998, Lidz, 1997). These two theories are often used to explain performance on cognitive tasks, specifically by identifying ability areas represented by test performance.

The psychometric or structural approach seeks to identify stable population-level traits or competencies based on individual differences in cognitive test performance

(McGrew & Flanagan, 1998). Correlational methods (e.g., factor analysis) are used to identify latent ability domains within and across psychological tests. Thus, dimensions of individual differences can be discerned, and test-takers placed at different points along one or more such dimensions on the basis of their test performance relative to that of the population. While psychometric approaches fail generally to explain cognitive *processes*, emphasizing, instead, the structure of latent abilities and description/classification of individual test-takers, models of intelligence based on this approach have the longest history of empirical support, and have also produced the most popular measures of intelligence in practice settings (McGrew & Flanagan, 1998). The first major psychometric theory was Spearman's Theory of Two Factors (Spearman, 1904). Spearman (1904) suggested that there was a general intelligence (*g*) which accounts, generally, for individual differences in cognitive performance, and a second factor relating to a specific ability (*s*) in some domain of intelligence, i.e., distinct from general intelligence. In this theory, performance on all cognitive tasks should correlate, to a greater or lesser degree, with *g*. The test score variance that is unaccounted for by this relationship comprises *s* (assuming no measurement error). Spearman's model was essentially a single-factor model (Herrnstein & Murray, 1994; Fraser, 1995), suggesting that intelligence is a unitary ability with variation across individuals due primarily to genetic differences (Fraser, 1995; Guthrie, 1998; Jensen & Inouye, 1980).

Cattell subsequently developed a dichotomous model of intelligence, *Gf-Gc* (Horn & Noll, 1998; McGrew & Flanagan, 1998). This model defined two different types of intellectual abilities, fluid intelligence (*Gf*) and crystallized intelligence (*Gc*). *Gf* consisted of inductive and deductive reasoning abilities, while *Gc* consisted of a person's knowledge (McGrew & Flanagan, 1998). Horn further developed the *Gf-Gc* model, resulting in the Horn-Cattell *Gf-Gc* model, by adding cognitive abilities to Cattell's original dichotomous model. With multiple additions, Horn's *Gf-Gc* model ultimately contained 10 intellectual ability factors (Horn & Noll, 1998; McGrew & Flanagan, 1998). Further factor analytic research proposed additional factors above and beyond the Horn-Cattel *Gf-Gc* model. Carroll (1993) set out to structure and develop a model for which these findings could be incorporated. Carroll proposed a hierarchical model of intelligence with three levels: stratum III (*g*), stratum II (broad abilities), and stratum I (narrow abilities). In Carroll's model, *g* is the overarching cognitive ability, stratum II abilities represent different intellectual domains within *g*, and stratum I abilities represent specialized intellectual abilities within each broad domain (Carroll, 1993). Stratum II contained the set of intelligences familiar to most professional psychologists today, e.g., "*Gv*", representing visual-spatial ability, "*Gs*" representing speed and efficiency of simple information processing, etc. Stratum I contains more specific cognitive processes deemed relevant to their superordinate Stratum II abilities. For example, inductive and deductive reasoning skills were deemed essential, among other specific skills, to solving complex novel problems, which is the domain of Fluid Reasoning (*Gf*). Using factor analytic methods, Carroll demonstrated strong correlated intellectual abilities across strata. Subsequently, McGrew (1997) and McGrew and Flanagan (1998) integrated the Horn-Cattell and Carroll's *Gf-Gc* models for the specific purpose of "cross-battery assessment." Within this model, *g* was eliminated and broad domains were condensed based on practical and factor analytic research (McGrew & Flanagan, 1998). Their work produced a model which was empirically driven, yet also simplified for a specific purpose and thus not incorporating all aspects that were theoretically and/or empirically supported.

Inductive Reasoning

Numerous factor analytic studies have found *Gf* (fluid reasoning) to have the strongest loading on *g*, making it a critical top measurement of general intelligence. Thus, narrow intellectual abilities falling within *Gf* have become an important area within assessment research. One such area is reasoning, which has historically been held central to the concept of intelligence (e.g., Spearman). The definition of reasoning may encompass different tasks and abilities, such as induction, deduction, planning, or judgment. While factor analytic research has found reasoning ability to load on *Gf* and *Gc*, it most closely and consistently loads on Gf (Carroll, 1993). Within the *Gf*-*Gc* model, the stratum I ability of induction (*I*) is of specific importance to the present study. Inductive reasoning typically involves tasks in which the participant is to induce a rule or common characteristic after assessing a set of one or more stimuli (Carroll, 1993). Inductive reasoning tasks/stimuli involve at least one deductive step, in eliciting a conclusion or response (Carroll, 1993). There are many different types/presentations of inductive reasoning tasks, i.e., number or letter sequence tasks, where the solver induces the rule governing changes from one element in a sequence to the next, matrix completion tasks, which require the solver to induce the changes across rows and columns in order to identify a missing element, etc.

Inductive reasoning may manifest in a number of different solution strategies. Liang, Jia, Taatgen, Zhong, and Li (2014) found that depending on the inductive reasoning task, different strategies were used to solve a given problem. For example, in the number series tasks, a retrieval strategy was used, meaning there was a direct retrieval of knowledge to induce the relationship between stimuli (Liang et al., 2014). Alternatively, in the letter series tasks, a procedural strategy was used, meaning there were multiple relationships induced to arrive at the relationship between stimuli (Liang et al., 2014). Thus, depending on the strategy used to solve an inductive reasoning task, there may be more steps and an increased workload on the participant.

Similarly, Carpenter, Just, and Shell (1990) found that participants utilized a multistep approach while solving matrix stimuli (i.e., an inductive reasoning task). The researchers looked at processes that differentiated high and low scorers on the Ravens Progressive Matrices (RPM) test (Carpenter et al., 1990). They found that both high and low scorers utilized an incremental reiterative strategy for encoding and inducing the regularities in each problem; however, high scores showed an increased ability to induce abstract relationships (Carpenter et al., 1990). This difference between high and low scorers reflects a goal management process, in which people with better inductive reasoning ability were able to solve the subgoals, even if they were less obvious, of matrix reasoning tasks to achieve the larger goal of solving the whole problem. This means that to solve all matrices, participants broke down the problem into smaller parts and solved the smaller parts one at a time; participants then used these solutions to solve the larger matrix stimuli. Additionally, induction of rules consisted of a comparison between elements that were next to one another (Carpenter et al., 1990). Based on these findings, solving matrix tasks involves a multi-step procedural strategy, as multiple relationships must be induced to solve the entire matrix stimuli. Implications of this complex process on working memory will be discussed later.

Matrix Tasks

Matrix tasks are a popular format for measuring inductive reasoning ability, fluid reasoning, and general intellectual ability in basic and applied research and clinical and educational assessment. They are currently included in the most current versions of the Wechsler Adult Intelligence Scale-Fourth Edition (WAIS-IV), Wechsler Intelligence Scale for Children-Fifth Edition (WISC-V), Raven's Progressive Matrices (RPM) (e.g., Colour Progressive Matrices (CPM), Standard Progressive Matrices (SPM), and Advanced Progressive Matrices (APM), numerous independent intelligence measures, online training programs, etc. (Raven, Raven, & Court, 1998; Wechsler, 2008; Wechsler, 2014). In matrix tasks, stimuli are presented in matrices (i.e., square or triangular) (Carroll, 1993). The items within the matrix can be literal, numerical, semantic, or figural in nature (Carroll, 1993). Thus, an unlimited variety of stimulus elements may be used within the basic format to generate test items. As with other inductive reasoning tasks, the solver identifies the order/trends/systematic changes across both rows and columns within the matrix (Carroll, 1993). Rules defining how the stimuli change across rows and columns may vary in difficulty (Carpenter et al., 1990; Carroll, 1993). The participant's ability to induce these rules is assessed by their selection of a stimulus that would fit into a missing/blank position within the matrix (Carroll, 1993), usually drawn from a set of distracters.

Raven's Progressive Matrices (RPM) are considered to be an exemplary assessment of inductive reasoning ability, as the task can be used to assess intellectual efficiency and conceptual ability, while limiting the verbal and manipulative abilities required by the participant (Alderton & Larson, 1990; Lezak, 2004; Mills, Ablard, & Brody, 1993). Carpenter et al. (1990) identified five different types of rules within RPM which may be combined in different ways within the same matrix task. Test takers participate in what Carpenter et. al. (1990) described as "correspondence finding," this is the process of determining which elements or features in a row are governed by the same rule. Sometimes these cues are ambiguous, as several features may be governed by multiple rules and may not follow a linear pattern. Carpenter et al. (1990) explained there are multiple ways in which matrices become more difficult to solve; i.e., the complexity of correspondence finding, type of rule, and the number of rules in play. The last two will be described more thoroughly in the following section.

Defining characteristics of matrix tasks. To simplify discussion of the salient functional components of a matrix task, these will be defined below as elements, features, and rules. To further simplify the discussion, we will refer exclusively to 3x3 matrices (as illustrated in Figure 1, composed of nine elements arranged in three rows and three columns), as these types of matrices appear so commonly in research and applied contexts, and are represented in the nearly ubiquitous RPM.

Elements. A matrix element is the shape, letter, number, etc., comprising one cell of a matrix. In Figure 1, nine elements are displayed.

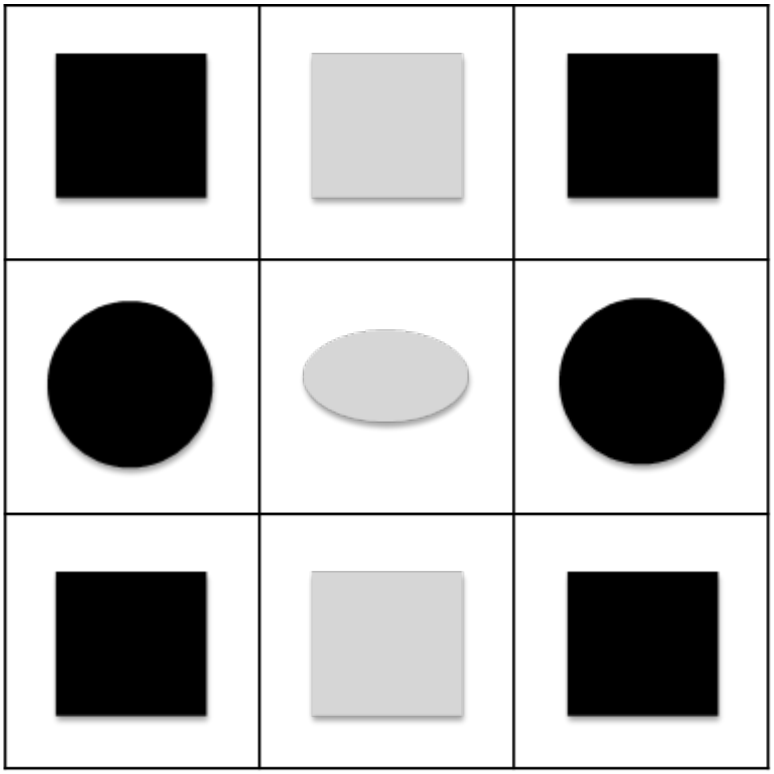


Figure 1. Example of a simple matrix completion task, with the missing element (typically lower left cell) filled in.

Features and identities. In matrix tasks, features are the physical/visual dimensions of individual elements within a matrix. As indicated previously, these can come in potentially endless forms with four major categories: literal, numerical, semantic, or figural (Carroll, 1993). Additionally, each feature will have at least two identities; an identity describes the possible physical/visual dimension for each feature. For example, if a feature was length, possible identities for this feature could be 2in., 4 in., or 6 in. In Figure 1, the *features* are shape and color, with two possible *identities* for shape (square and circle) and two *identities* for color (black and grey). Features are informationally constrained by the range of possible identities.

Rules. In matrix tasks, rules are predetermined ways in which *identities of features change across elements* within a row or column. In each matrix, one rule may be applied to the rows and the same or a different rule may be applied to the columns. For example, in Figure 1, the feature of shape (identity = square or circle) varies by row, while the feature of color (identity = black or grey) varies by column. The rule governing color dictates that "grey" will be the identity of the center element of each row; the rule governing shape dictates that "circle" will be the identity of the center element of each column. Note also that in Figure 1, color does not vary across elements in columns, and shape does not vary across elements in rows; while this could be interpreted as a rule dictating that shape is the same across rows and another rule that color is the same across columns, such rules are, by definition, informationally redundant (Pomerantz & Lockhead, 1991) with the first two stated rules (i.e., the first two rules completely define the matrix in the absence of the two "same" rules), and, as such do not necessarily need to be stated.

Using regression analysis, Carpenter et al. (1990) found that the total number of rules in a matrix accounted for 57% of the variance in mean error rates, and as the number of rules increases response times for correct responses were longer. These results indicate that the number of rules within a matrix stimuli affected performance, both inability to correctly answer the item and the amount of time to arrive at an answer. Vodegel, Matzen, van der Molen, and Dudink (1994) assessed how rule type, the number of elements, and answer distractors impacted performance on a matrix task. They found that the number and type of rules accounted for 63% of the variance in item difficulty (Vodegel et al., 1994). Jia, Liang, Shi, Wang, and Li (2015) found increased activations in the right dorsal lateral prefrontal cortex and medial posterior parietal cortex of the brain when rule complexity (simple to complex induction) was increased in an inductive reasoning task (number series task). Thus, as rule complexity increases, so does activity in these two areas of the brain (i.e., more complex rules may require more mental activity). The findings from these studies indicate that as rule complexity and the number of rules increases, inductive reasoning tasks become more difficult for participants to solve and require more mental effort.

Rules are applied to element features across rows and columns. Features can be combined in rows and/or columns, as well as, changing or held constant (same identity for all elements) within a matrix stimulus. In contrast to understanding how rules affect performance, relatively little research has elucidated the relationship between features and performance. Primi (2001) found that element's "perceptual organization," grouping of elements within a matrix cell, in relation to Gestalt principles, accounted for 53% of the variance in item difficulty. Specifically, Primi (2001) found "nonharmonic" (incongruent elements, i.e., conflicting combinations of visual and conceptual information/elements, both of which must be addressed to solve a matrix) to be more difficult to solve within a matrix. Meo, Roberts, and Marucci (2007) added to this line of research by finding that when elements contain overlapping and/or unfamiliar shapes, the matrix becomes harder to solve, *element salience hypothesis*. Within both of these studies, the features do not change; rather the features are more or less obscured. The participant's ability to identify the features that rules are applied to is influenced, rather than the differential impact of feature type. Thus, these findings may relate more to a participant's visual-spatial (*Gv*) ability, than their fluid reasoning (*Gf*) ability. No research since the Meo et al. (2007) study has assessed the impact of feature on performance within matrix tasks.

Working Memory/Goal Management

As previously described, matrix tasks implicitly require aspects of inductive and deductive reasoning when eliciting an answer from a participant. Additionally, working memory is used when solving a matrix task because the participant must remember rules and how they interact to solve the task. Kyllonen and Christal (1990) found a correlation (*r* from .80 to .90) between working memory capacity and different reasoning ability factors through confirmatory factor analysis. Carpenter et al. (1990) used the Tower of Hanoi, an executive functioning task that also requires working memory, to assess working memory in solving Raven's matrix problems. They found a significant correlation ($r(43) = .77$, $p < .01$) between participant's errors on the Raven test and the total number of errors on the six Tower of Hanoi puzzles. Carpenter et al. (1990) concluded that because errors on the Tower of Hanoi puzzle reflect working memory abilities, the significant correlation they found with errors on the Raven's test suggests that this task also requires working memory. These findings suggest that individual differences on the Raven's test may be linked to one's ability to generate and manage goals in working memory; therefore, "goal-management" impacts performance on the

Raven's Matrices (Carpenter et al., 1990). Liang et al. (2014) augmented Carpenter et al.'s (1990) work by finding increased working memory demands, through MRI data, depending on the strategy used to induce rules in an inductive reasoning task. For inductive reasoning tasks that require procedural strategies, like matrix tasks, there may be increased working memory demands on the participant, as shown through increased activation of cortical regions associated with memory retrieval and mental representation (Liang et al., 2014). Additionally, inductive reasoning tasks that required retrieval strategies—direct retrieval of knowledge—use the same cortical areas of the brain as those that require procedural strategies; however, cortical activation in these areas is lower, indicating lower working memory demands (Liang et al., 2014). Essentially, these researchers found that some types of inductive reasoning tasks (letter series) may require increased working memory demands to manage and manipulate rules that cannot be solved through direct retrieval processes.

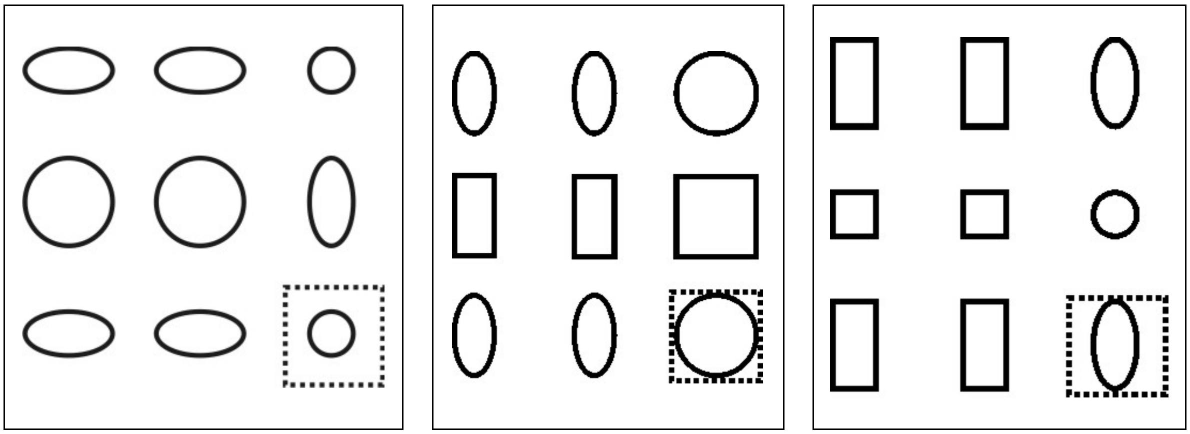
Carpenter et al. (1990) suggested that the addition of more rules to a matrix task does not necessarily affect a participant's ability to induce the rule, but rather requires greater goal-management ability. This means that the more rules in play; the more working memory is required to "construct, execute, and maintain" these goals to find the solution to the matrix task; referred to as the "number-of-rules account" (Carpenter et al., 1990; Harrison, Shipstead, & Engle, 2015). Therefore, goal-management is expressing one's ability to generate and maintain goals in working memory. Using Raven's Matrices, Smolen and Chuderski (2015) found a quadratic relationship between performance on this task and working memory as assessed by mean scores on the operation, reading, and symmetry span tasks. Thus, for Raven's items with little to moderate difficulty (between floor and ceiling), there is a positive relationship between working memory and performance. However, on high difficulty Raven's items (ceiling) this relationship will decrease, trending toward non-significance. Additionally, there has been some debate if working memory is more highly correlated when rules are repeated or when novel rules are presented in consecutive matrix tasks, rather than based on number of rules in play as Carpenter et al. (1990) proposed (Harrison et al., 2015; Wiley, Jarosz, Cushen, & Colflesh, 2011). Harrison et al. (2015) concluded that working memory is more highly associated with repeated rule presentation, than novel rule presentation. These findings support a "learning efficiency account" (Harrison et al., 2015) of the relationship between working memory capacity and Raven's performance, rather than an "interference/distraction account" (Wiley et al., 2011) or "number-of-rules account" (Carpenter et al., 1990) proposed by previous research. Essentially, rather than working memory *inhibiting* previously-used rule combinations that would have otherwise interfered with performance on the current matrix problem ("interference/distraction account"; Wiley et al., 2011). Harrison et al. (2015) suggested that working memory aids participants in *retrieving* previous matrix solutions to solve the current ones ("learning efficiency account"). While most research supports a relationship between matrix task performance and working memory, there is currently no consensus as to the nature of this relationship. For the purposes of the current study, goal management/working memory will not be assessed.

Purpose of the Present Study

To date, no study has identified the impact of rules on matrix task performance independent of the features to which they are applied. Primi (2001) has demonstrated that by altering the physical appearance of individual elements, performance on matrices with identical rules can be changed, suggesting that by making features less visually salient, the relationship between rule complexity/number and performance may be moderated. However, Primi's (2001) matrices were designed specifically to ambiguate features, and rules that applied to these features were not altered systematically. It remains an open question whether features typically employed in matrix tasks, absent manufactured visual ambiguity, influence task performance apart from the rules that affect them. If not so, i.e., if only rule complexity and number influence performance irrespective of features, then it should be possible to design, a priori, alternate forms of existing matrices, so long as the rules may be sensibly applied to more than one feature, where the two forms of the test retain identical informational demands, but "look" entirely different. Miller et al., (2009) demonstrated that practice effects may be reduced in a block design task by presenting visually non-identical designs with identical informational demands, versus presentation of the same designs, as in a typical test-retest paradigm. It may be possible to reduce the practice effects in such widely-used measures of fluid ability as matrix completion tasks by using the same method, assuming that rule-identical matrices with different features produce an identical performance.

The purpose of this study is to see if varying the features to which rules are applied in an inductive matrix reasoning task has an effect on performance if the rules themselves are held constant, i.e., to see if performance differences can be elicited by applying the same sets of rules, systematically, to different features. If features influence performance irrespective of rules, then we would expect to see overall performance differences between the Presentation groups of the Experimental Inductive Matrix Reasoning Task (EIMRT). It is predicted that no significant performance differences on the EIMRT will be found. For the purpose of this study, a feature will be defined as the visual dimensions to which rules can be applied. Three features will be manipulated: shape, width, and height. Within each matrix, each element can take on one of two identities for each feature (i.e., for shape, the element may be either round or square; for height, it may be either tall or short; for width, it may be either wide or narrow). Thus, each matrix element may have one of eight possible appearances (e.g., short, wide, & square; tall, narrow, & round, etc.).

Three different rules will be used in the study's matrices: same, symmetrical, and 2/3, and, depending on the matrix, a rule may be applied to any feature, dictating that feature's change across elements in either a row or a column. For example, the same rule (SAME) applied to "shape" (a feature) in a row would mean that all elements in any given row would be either round or square. If the rule were "symmetrical" (SYM), applied to the same feature in rows, then the identities would be distributed symmetrically with a row – either the middle element would be square and the outside elements round, or vice-versa. If the rule were "two out of three" (2/3), then the identities would be distributed across the row asymmetrically, e.g., the left element in the row would be square, the middle element in the row would be square, and the right-hand element in the row would be round.



Matrix A | Matrix B | Matrix C

Feature	Rule in: Row	Column
Shape	SAME	SAME
Height	SAME	SYM
Width	2/3	SAME

Feature	Rule in Row	Column
Height	SAME	SAME
Shape	SAME	SYM
Width	2/3	SAME

Feature	Rule in Row	Column
Width	SAME	SAME
Height	SAME	SYM
Shape	2/3	SAME

Figure 2. Example of three matrices with identical rules applied to different features. Rules are SAME (identity does not change in that row or column), SYM (identity is different in the middle element of that row or column, and 2/3 (one of the identities in that row or column is different, though the distribution in that row or column is not typically symmetrical).

Figure 2 illustrates an example of three matrices with identical rule combinations applied across row and column, applied to different features. In all three cases, the same rules are applied. In rows, two features follow the SAME rule, and a third feature follows the 2/3 rule; in columns, two features follow the SAME rule, while a third feature follows the SYM rule. In all three cases, one feature follows the SAME rule in both row and column, another feature follows SAME in rows but SYM in columns, and the third feature follows 2/3 in row and SAME in columns. If the number and complexity of rules are the sole determinants of task performance, then negligible performance differences should be observed between these three matrices. If different features elicit performance differences, then matched sets of items, like those in Figure 2, should evidence measurable differences in task performance.

CHAPTER II

METHOD

Participants

Participants were 196 undergraduate students (126 females and 70 males) recruited through the SONA system in conjunction with the undergraduate psychology class research requirement. Of study participants, 96.9% were not Hispanic or Latino, 1.5% were Hispanic or Latino, and 1% were unknown. Regarding participants' race, 92.3% identified as White, 1.5% Asian, 1.5% Black or African American, 1% American Indian, 1% Black or African American and White, .5% Asian and White, .5% Native Hawaiian or other Pacific Islander and White, and 1% other. The mean participant age was 19.487 (range = 18 - 29, *SD* = 1.84). Regarding participants' highest achieved education, 56.6% achieved a high school diploma, 31.1% less than a 2 or 4-year college degree, 5.6% an Associates (2-year) degree, 4.6% a Bachelors (4-year) degree, 1.5% a GED or high school diploma equivalent, and .5% less than a Master's degree. Participants' reported overall mean GPA was 3.45 (range: 1.9 - 4.152, *SD* = 0.47).

Materials

Demographics

There were two sets of demographic questionnaires. The first consisted of background questions regarding age, gender, race, GPA, and highest grade completed. In the second demographic questionnaire, the participants were asked if they have had any previous psychological testing, and, if so, if the psychological testing occurred in the past 6 months. There were additional questions in this second questionnaire to assess for visual or motor impairments and for any history of a neurological disorder that might impact visual processing or motor performance (e.g., Parkinson's disease, attention-deficit/hyperactivity disorder, learning disorder, head injury, Multiple Sclerosis, etc.).

Symbol Series Task

In this task, Symbol Series Task, participants induced the rule applied to a linear set of symbols (Levy & Levy, 1989). They then selected the next symbol in the series from five answer options. For each item, there is only one rule and one feature present. Participants' responses for each item were scored as 1 or 0, with a score of 1 used to indicate a correct response or 0 used to indicate an incorrect response or no response for an item. A sum of the 27 item scores was calculated for the participant's total score on the Symbol Series Task. This task is identical to series completion tasks described by Carroll (1993) as representing a test of inductive reasoning. Participants' score on this measure was used as an independent measure of inductive reasoning ability, to ensure inductive reasoning abilities across the three participant groups at the time one performance are not significantly different.

Experimental Inductive Matrix Reasoning Task

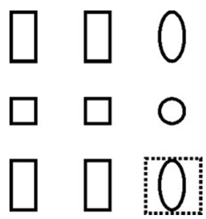
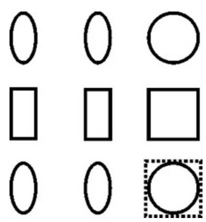
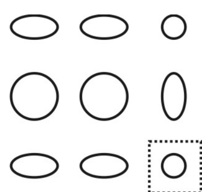
Matrix reasoning tasks are used to measure inductive reasoning (Carroll, 1993). The participant was required to analyze a set of incomplete matrices, and select the missing element from a set of eight options. In each matrix, one of three rules (SAME, SYM, 2/3) was applied to each feature (height, width, shape) in both columns and rows. Table 1 displays the possible combinations of rules applied to columns and rows for a single feature. Because the number of designs resulting from all possible combinations of the nine rule by row/column sets (see Table 1*)* and the three features would be prohibitively large ($9^3 = 729$), we determined to constrain the possible combinations by, in each of three sets, holding one feature to SAME in both column and row. The result was three sets of 81 designs each (see Table 2). In one set, all possible rule combinations are applied to height and width, to width and shape in the second, and, to the third set, shape and height. Thus, in any of the three sets of matrices, one matrix is identical to a matrix from each of the other two sets with respect to the combination of rules applied to row and column. Participants' responses for each item were scored as 1 or 0, with a score of 1 indicating the participant selected a correct response and a score of 0 indicating the participant either selected the incorrect response or provided no response for an item. A sum of the 81 item scores was calculated for the participant's total score on the EIMRT.

Table 1
Possible Combinations of Rules Applied to a Single Feature Across Row and Column of the EMIRT.

	Row		
Column	*Same*	*Symmetrical*	*2/3*
Same	Same by Same	Same by Symmetrical	Same by 2/3
Symmetrical	Symmetrical by Same	Symmetrical by Symmetrical	Symmetrical by 2/3
2/3	2/3 by Same	2/3 by Symmetrical	2/3 by 2/3

Table 2

EMIRT Presentation Sets.

Set	Description	Example
1	Shape by Height (Width held constant)	
2	Shape by Width (Height held constant)	
3	Height by Width (Shape held constant)	

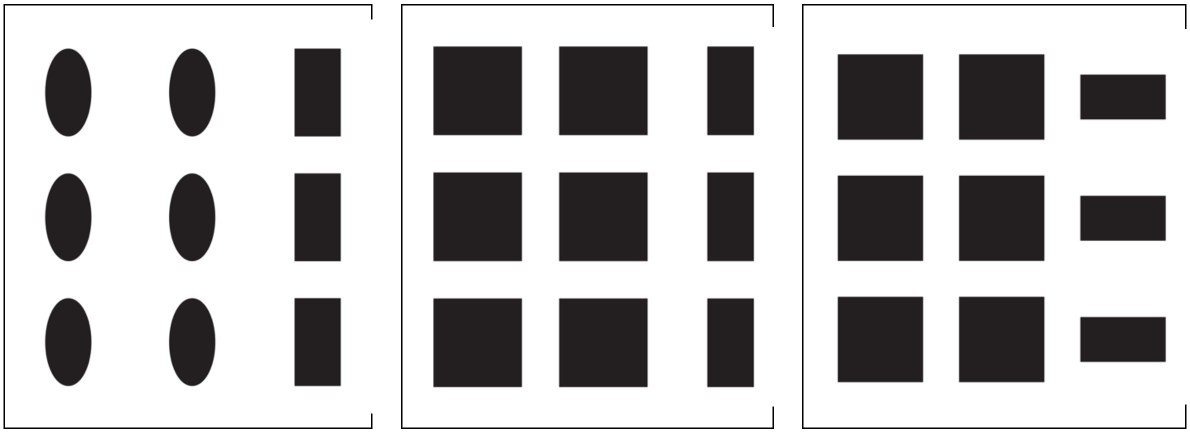
Procedure

Participants completed all components of the study on Qualtrics. Informed consent was procured online via Qualtrics. Participants completed both sets of demographic questions and the symbol series task. Then participants were randomly assigned to one of three experimental groups, corresponding to the three presentation groups of the EIMRT (see Table 2). Participants completed the 81 items of their assigned experimental matrix set. Presentation order within each set was randomized for each participant. Once the participants completed these items their participation in the study was complete. University of North Dakota (UND) participants, who were enrolled in 100- or 200-level undergraduate psychology courses, received one credit (i.e., one credit for every hour they participated in the current study) towards their research participation requirement, as the study was estimated to take approximately 1 hour (i.e., demographics=10 minutes, Symbol Series Task=5 minutes, EIMRT = 40.5 minutes). All participants were entered into a raffle, which was drawn once data collection was completed. The participant who correctly completed the most matrices received a prize independent of the raffle drawing.

CHAPTER III

RESULTS

Prior to data analysis, participants were eliminated from the data set for a variety of reasons. Thirty-nine participants' responses were removed for ending the survey before viewing every item. Five participants were removed because their age was 30 or more. Participants with inadequate effort on the EIMRT were eliminated from the dataset. Inadequate effort was assessed through the participants' percent correct on same by same rules matrix items (9 items for each participant), as this rule combination should be trivially easy for the participants to identify and solve (see Figure 3 for an example of a same by same rule matrix across Presentation sets), and total completion time of survey falling below 15% of the estimated study completion time (i.e., 9 minutes' total completion time). The proposed completion time effort measure did not eliminate any participants from the current study. The nine same by same rules matrix items were randomly presented throughout the total 81 matrices participants completed, ensuring assessment of effort throughout the EIMRT. Thirty-eight participants were excluded from data analysis for inadequate effort, percent correct lower than 100% (9 out of 9 correct) on the same by same rule matrices on the EIMRT. This effort criterion was increased from the proposed 67% (6 out of 9 correct) on the same by same rule matrices on the EIMRT, as these items were considered to be trivially easy, thus poor performance on any of these items likely indicated inadequate effort throughout the EIMRT.



Shape/Width **Width/Height** **Height/Shape**

Feature	Rule in: Row	Column
Height	SAME	SAME
Shape	2/3	SAME
Width	SAME	SAME

Feature	Rule in Row	Column
Shape	SAME	SAME
Width	2/3	SAME
Height	SAME	SAME

Feature	Rule in Row	Column
Width	SAME	SAME
Height	2/3	SAME
Shape	SAME	SAME

Figure 3. Example of three matrices with identical same by same rule combinations applied to different features, which was used as an effort measure. Rules are SAME (identity does not change in that row or column), SYM (identity is different in the middle element of that row or column, and 2/3 (one of the identities in that row or column is different, though the distribution in that row or column is not typically symmetrical).

Group-wise differences on demographic data were assessed. No differences were observed with respect to age, $F(2, 182) = 1.237$, $p = .293$, $\eta_p^2 = .013$; ethnicity, $\chi^2 (6, N = 196) = 5.012$, $p = .542$; race, $\chi^2 (16, N = 196) = .13.510$, $p = .635$; gender, $\chi^2 (2, N = 196) = .382$, $p = .826$; highest level of education earned, $\chi^2 (10, N = 196) = 14.265$, $p = .161$; estimated family income level, $\chi^2 (32, N = 196) = 27.893$, $p = .675$. One group-wise difference was observed with respect to reported GPA, $F(2, 180) = 3.313$, $p = .039$, $\eta_p^2 = .036$. Subsequent pairwise comparisons revealed that participants' reported GPA in the width/height Presentation group was significantly ($p = .033$) higher than that of the shape/width Presentation group, with no other significant differences observed between

Presentation groups. See Table 3 for group-wise differences on psychological and/or health related demographic variables, which may impact cognitive performance. One group-wise difference was observed between Presentation groups on multiple sclerosis.

Table 3

Presentation Group Differences on Self-Reported Psychological and Health Demographic Items

	Presentation Group			
Demographic Item	*Shape/Width*	*Width/Height*	*Height/Shape*	$\chi^2_{(df = 2)}$
Attention Deficit Hyperactivity Disorder	4.5%	3.0%	1.6%	.975
Learning Disorder	0%	1.5%	1.6%	1.027
Mood Disorder	13.6%	7.6%	12.5%	1.372
Anxiety Disorder	15.2%	9.1%	12.5%	1.134
Obsessive Compulsive Disorder	1.5%	1.5%	1.6%	.001
Panic Attacks	4.5%	1.5%	3.1%	1.022
Asperger's	3.0%	1.5%	0%	1.980
Autism Spectrum Disorder	0%	1.5%	0%	1.980
Pervasive Developmental Disorder	0%	0%	0%	
Oppositional Defiant Disorder	0%	0%	0%	
Conduct Disorder	0%	0%	0%	
Diabetes	3.0%	1.5%	0%	1.980

Table 3 Cont.

	Presentation Group			
Demographic Item	*Shape/Width*	*Width/Height*	*Height/Shape*	χ^2 (df = 2)
Lupus	1.5%	0%	0%	1.980
Seizure Disorder	1.5%	0%	1.6%	1.027
Neuropathy	0%	0%	0%	
Multiple Sclerosis	4.5%	0%	0%	6.001*
Brain Tumor	0%	0%	0%	
Stroke/CVA	0%	0%	0%	
Trauma Brain Injury/Concussion	4.5%	1.5%	4.7%	1.224

Note. Within-group percentages of occurrences are reported for demographic items. No Chi-squared analysis was performed for demographic items with zero instances reported by participants across groups.
**p* < .05. ***p* < .01. ****p* < .001.

The relationship between performance on the Symbol Series Task and the EIMRT was examined using Pearson's correlations, in order, to establish its utility as a covariate in further analysis. Mertler and Vannatta (2010) suggest the dependent variable and the prospective covariate should theoretically or statistically (significantly) correlate. Establishing the correlation in this analysis aids in justification of removing the variance associated with the covariate (performance on the Symbol Series Task, i.e., individual inductive reasoning ability) from the dependent variable (performance on the Experimental Matrix Reasoning Task). Participants' performance on the Symbol Series Task was positively correlated with EIMRT performance, $r(196) = .439$, $p < .001$, indicating that in this sample 19.3% of the variance in EIMRT performance may be explained by participants' performance on the Symbol Series Task. Both tasks appear consistent with Carroll's (1993) description of an inductive reasoning task and Symbol Series Task performance will be used as a covariate in later analyses for EIMRT performance.

A one-way fixed factor analysis of variance (ANOVA) was performed on the Presentation groups. The design of this analysis included one between-subject factor of Presentation group with 3 levels (a) height/shape (b) shape/width (c) height/width. The dependent measure was participants' inductive reasoning task score on the Symbol Series Task. No group-wise differences in inductive reasoning ability between the three groups was found, $F(2, 193) = .264$, $p = .768$, $\eta_p^2 = .003$.

For the primary analysis, a one-way fixed factor analysis of covariance (ANCOVA) was performed on the Presentation groups' EIMRT performance. The design of this analysis included one between-subject factor of Presentation group with 3 levels and one covariate (individual performance on Symbol Series Task). The dependent measure was the EIMRT score. There was a significant effect of Presentation group on EIMRT score, $F(2, 193) = 4.871$, $p = .009$, $\eta_p^2 = .048$. Subsequent pairwise comparisons, using estimated marginal means to account for the inclusion of the covariate within the prior analysis, revealed that participants' performance in the width/height Presentation group was significantly ($p = .007$) lower than that of the height/shape Presentation group, with no other significant differences observed between

Presentation groups. See Table 4 for all post-hoc comparisons between Presentation groups.

Table 4

Post-hoc Pairwise Comparisons Between Presentation Groups

Presentation Group Comparison	Difference between Means
Shape/Width versus Width/Height	1.717
Shape/Width versus Height/Shape	1.257
Width/Height versus Height/Shape	2.975**

Note. Estimated Marginal Means were used in Bonferroni corrected post-hoc pairwise comparisons.
*$p < .05$. **$p < .01$. ***$p < .001$.

CHAPTER IV

DISCUSSION

Previous research by Primi (2001) and Meo et al. (2007) altered participant's ability to identify the features that rules were applied to by visually ambiguating features, as previously discussed. The present study aimed to assess the relationship between rules and features by systematically varying features between Presentation groups. To accomplish this, the present study included one element within each cell of matrix tasks, instead of multiple elements. Each element had one rule applied in row and another in column for each of two features. The visual ambiguity produced by grouping multiple elements, overlapping elements, and/or having unfamiliar shapes within each cell and/or matrix was eliminated from the present study to allow for a clearer understanding of the impact of differing features on matrix task performance. While previous research may have been impacted by a test taker's visual-spatial (*Gv*) ability and fluid reasoning (*Gf*) ability, the present study was designed to test the impact of feature on matrix reasoning task performance. It was assumed no significant results would be found, indicating the features to which rules are applied does not impact performance within matrix tasks.

The results of the present study suggest matrix reasoning performance may be differentially impacted by the features to which rules are applied. The design of the present study allowed us to assess the impact of features (i.e., shape, height, width) on matrix reasoning task performance via Presentation groups (i.e., shape/width, width/height, height/shape), such that the rule combinations were identical across sets, and yet produced matrices that looked very different, owing to the differences in the features to which the rules were applied. The performance differences seen between Presentation groups indicate the height/shape had the highest scoring performance, with the shape/width scoring slightly lower, and the width/height scoring significantly lower and having the lowest mean score. These results suggest the Presentation groups of height/shape and width/height have a differential impact on matrix task performance. In both the lowest (width/height) and the highest (height/shape) performing groups, height varies by the same rule combinations, which may suggest either the features of width and shape have a differential impact on performance or the interaction of height with width and shape is differentially impacting performance. Features were assumed to be interchangeable; however, these findings suggest features differentially impact matrix task performance, even when the rule sets are identical.

Visual Salience and Efficiency

One possible explanation for this finding is that features may be differentially salient. The importance of element salience may extend beyond the Meo et. al. (2007) study, *element salience hypothesis*. While Meo et al. (2007) identified familiarity with elements as impacting performance on matrix tasks, as indicated by European vs. Invented letters, the current study suggests some features may be easier to identify and solve for participants, even when all features are readily familiar to participants. Previous research by Stevenson et al. (2014) found, in children, *what* features (i.e., object, color, quantity, and size) were more easily solved than *where* features (i.e., orientation and position). The researchers suggest *what* features are associated with ventral thought processes, while *where* features are associated with dorsal thought processes, the latter of which develops with age of the child (Stevenson et al., 2014). Older children were more readily able to identify *where* features as compared to younger children and children with less efficient working memory (Stevenson et al., 2014). Stevenson et al. (2014) suggest this may be representative of a shift in reasoning from "superficial perceptual features" to "relations between elements in the analogy." Within an adult population, these findings may translate into efficiency, meaning adults may initially attempt to identify and solve features and rules within matrix tasks using faster and easier thought processes and secondarily by more complex associations or thought processes. Yuan et al. (2012) found matrix task performance to be positively correlated with gray matter volume and regional homogeneity in brain areas, the dorsal anterior cingulate cortex and fronto-insular cortex, associated with the salience network. The salience network functions to detect salient stimuli from sensory input and initiate attentional signals to the central executive network, which mediate attentional control, like working memory and higher-order cognitive processes (Yuan et al., 2012). This attentional control allows for the relay of salient stimuli to the relevant cortical regions of the brain (Yuan et al., 2012). This network facilitates the stimulus to be salient beyond other sensory input. Yuan et al. (2012) findings suggest the salience network in the brain is an important factor facilitating fluid reasoning (*Gf*) ability. In adults, a more thoroughly developed salience network may make detection of familiar elements, then subsequent switching between thought processes to identify correct solutions more efficient, resulting in more correct matrix task solutions and better overall performance. The combined implications of the Stevenson et al. (2014) and Yuan et al. (2012) findings may suggest differential thought processes (dorsal versus ventral) may persist into adult test-takers, as they may innately detect and attend to *what* features and then subsequently attend to *where* features in solving matrix reasoning tasks. By this hypothesis, some features may be more efficiently attended to than other features, and thus may be more readily identified and used to inform the inductive-deductive process by test-takers.

Within the present study, the width/height Presentation group may have caused participants to induce unintended rules or aspects of features. The visual representation of rules is theoretically consistent throughout the Presentation groups, as the same rule combinations are applied to the Presentation groups, though there may be differing visual implications of combining the width/height features as compared to the shape/width and shape/height features. Participants may have visually induced unintended aspects, such as rotation or orientation, of the width/height Presentation group as additional or more complex rules within the matrix tasks, thus differentially impacting performance. The present study's finding may indicate that combining multiple *what* features may unknowingly cause participants to induce unintended *where* features within matrix items, representing more developmentally complex features as indicated by Stevenson et al. (2014). Within the present study, the width/height Presentation group may have caused participants to induce unintended rotational or orientation patterns. These results indicate that combining multiple *what* features may produce more complex and possibly unintended visual relationships, impacting test-takers performance. The implications of combining multiple features within an element are relatively unknown.

Limitations and Future Directions

One limitation of the current study relates to participants' reported GPA. Mean GPA was significantly higher in the width/height Presentation group than in the shape/width group. This finding may suggest differential intellectual abilities, motivation, discipline, etc. between experimental groups within the present study. Review of demographic data revealed that GPA may have been reported on different scales (i.e., 4.0 scale and above 4.0 scale) and at different academic levels (i.e., high school, technical college, and university levels) depending on how participants interpreted the demographic questionnaire. If true, reported GPA may not be a valid indicator of differential intellectual ability between experimental groups. Additionally, the width/height Presentation group's mean reported GPA was significantly higher than the shape/width group's GPA, while no significant differences between Presentation groups on the Symbol Series Task score were found. This may indicate that reported GPA captures differential variance in participants' intellectual abilities not directly assessed by the present study. Previous research has indicated small to moderate effects of GPA on matrix reasoning performance (Downey et al., 2014; McLaurin & Farrar, 1973; Rushton et al., 2004). Future studies should clearly define levels of GPA to be reported and/or conceptualize more appropriate overall measures of academic achievement between experimental groups.

With regards to multiple sclerosis (MS) self-report between Presentation groups, the shape/width group had significantly more participants with MS than the other two groups. Anagnostouli et al. (2015) found that MS patients performed significantly worse on measures of reasoning ability than healthy controls. This research suggests the MS presentation in participants may lower performance on reasoning tasks, as compared to healthy individuals. The shape/width group may have performed better if the current study had controlled for MS within this sample and differences in performance between the shape/width and width/height group may have been present. The participants reporting MS were removed and previous analyses were repeated. Participants' performance on the Symbol Series Task was positively correlated with EIMRT performance, $r(193) = .441$, $p < .001$. No group-wise differences in inductive reasoning ability (Symbol Series Task score) between the three Presentation groups was found, $F(2, 190) = .256$, $p = .774$, $\eta_p^2 = .003$. For the primary analysis, a one-way fixed factor ANCOVA, there was a significant effect of Presentation group on EIMRT score, $F(2, 190) = 4.817$, $p = .009$, $\eta_p^2 = .049$. Subsequent pairwise comparisons revealed that participants' performance in the width/height Presentation group was significantly ($p = .007$) lower than that of the height/shape Presentation group, with no other significant differences observed between Presentation groups. These findings suggest that while MS may impact performance on matrix reasoning tasks, the inclusion of participants with MS in previous analyses did not significantly change the results of the current study.

In the present study, participants' solutions were either correct or incorrect. A more complex scoring system may have more clearly highlighted the differential impact of features within the present study, as compared to the impact of Presentation groups. Future research should consider using a scoring system similar to that of Stevenson et al. (2014), which scored each feature independently for matrix items. This type of scoring system may more clearly indicate what features within a Presentation group participants had more difficulty identifying and solving. Additionally, future research should consider assessing the impact of individual features and their combinations to understand how the combination of features may create more difficult and possibly unintended aspects to matrix elements. The implications of combining features are relatively unknown. While previous studies have aided in identifying why individual features may be harder or easier to solve, they have not addressed the differential impact of feature combinations (Meo et al., 2007; Primi et al., 2001; Stevenson et al., 2014).

The present study did not directly assess working memory or cortical functioning. Previous research and the present study suggest implications of differential working memory ability and cortical functioning on one's ability to identify and solve features within a matrix reasoning task without direct assessment of these domains (Stevenson et al., 2014; Meo et al., 2007). Carpenter et al. (1990), Chuderski (2015), and Liang et al. (2014) found significant effects of working memory or cortical activation on matrix reasoning ability, though did not assess the impact of features on matrix reasoning performance. No study to date has directly assessed the impact of working memory ability and/or cortical function on feature identification and solution. Without direct assessment, the present study can only suggest implications of working memory ability and cortical pathways on feature identification and solution. Future researchers should consider assessing brain activity to assess the conceptualization of features as either using ventral or dorsal mental networks. Assessing working memory ability in addition to cortical functioning would enable future researchers to understand the differential and combined affects of these domains on feature identification and solution. This type of research could help validate theorized cortical networks associated with different types of features, suggested in the Stevenson et al. (2014) study, and determine whether these networks continue to be used in adult populations for differing features as suggested by the present study.

In conclusion, the present study aimed to clarify the impact of features on matrix reasoning performance. In our sample, we found the participants who completed matrix tasks with the width/height feature combination performed significantly lower than those who completed the height/shape feature combination. These findings indicate some features and/or feature combinations may be more efficiently solved, even when all features present are familiar or salient. Considering the limitations related to demographic variables, scoring, and working memory and cortical functioning assessment, future studies are warranted to address the effect of feature on matrix reasoning ability.

Appendix A
Consent Form

Informed Consent for the Sona-Systems Sample

INFORMED CONSENT
TITLE: A Study of Presentation Effects on Matrix Reasoning Scores
PRINCIPAL INVESTIGATOR: Katharine Lindberg (Master's Student, University of North Dakota)
SUPERVISOR: Joseph Miller, Ph.D. (Professor of Psychology, University of North Dakota)
PHONE #: 701-777-4472
DEPARTMENT: Psychology

RESEARCH STATEMENT

You have been invited to participate in a research study on factors that may affect matrix reasoning performance. If you remain interested, your participation will consist of answering a series of questions below about your life history and two sets of inductive reasoning tasks; requiring roughly 60 minutes. Your participation first requires your informed consent. This consent form that you are now reading provides information that describes this study and any risks involved in participation. Please take your time in making your decision as to whether or not to participate. If you choose to participate in this study, you are free to skip any questions that you would prefer not to answer. If you consent to participate after reading this form, enter your name in the text box and begin to respond to the questions that follow.

WHAT IS THE PURPOSE OF THIS STUDY?

You are invited to be a participant in this research study examining factors that may affect matrix reasoning performance. You have been given an opportunity to participate as a student at the University of North Dakota.

HOW MANY PEOPLE WILL PARTICIPATE?

Approximately 174 students will participate in this study.

HOW LONG WILL I BE IN THIS STUDY?

This is a single session study expected to require approximately 60 minutes. You are expected to complete this testing immediately after affirming the consent requested for your participation at the end of this form.

WHAT WILL HAPPEN DURING THIS STUDY?

If you agree to be in this study, the following will happen:

You will be asked to complete a series of questions about a variety of topics, including relevant medical history which has been historically shown to impact cognitive tasks. These series of questions will follow this consent form. Your participation and completion of the testing will be documented in the electronic system known as Qualtrics.

You are permitted to leave any items blank for any reason you choose (including a belief that the requested information is unduly personal). You may withdraw from the study at any time by discontinuing completion of the requested items. At the end of the survey, you will be given credit on Sona-Systems for your participation.

WHAT ARE THE RISKS OF THE STUDY?

You may become fatigued over the course of the study. You may feel as though you are not performing well on test items over the course of the study. You are not expected to be able to answer every question correctly, rather to do your best personal performance. Performance on these measures are expected to be variable. Such risks are minimal. If, however, you become upset by questions or procedures, you may stop participation at any time or choose not to answer a question. Any action taken to alleviate personal distress over any survey question must occur at your expense.

BENEFITS OF THIS STUDY

The benefits of this study include the increased knowledge of how various factors may influence matrix reasoning performance. This information may be helpful to professionals in the field, while also serving to advance the objectives of research being conducted by other future investigators in the field.

WILL IT COST ME ANYTHING TO PARTICIPATE IN THIS STUDY?

You will not have any direct costs for being in this study, other than the time involved to complete the survey.

WILL I BE PAID FOR PARTICIPATING?

If you choose to enter your email address at the beginning of the study, you will be eligible to win one of three $20 gift cards from Amazon. The three participants with the highest scores on the matrix task will receive the three gift cards. There will be 3 gift cards available. Your odds of winning a gift card are no less than 1 in 58.

All survey responses will be de-identified immediately, and your email address will only be used for the purposes of contacting these three winners. They will not be used for future solicitation, communication, or identification.

Students participating for course credit will be awarded one hour of credit at the end of the survey.

WHO IS FUNDING THE STUDY?

The gift cards are being purchased by the researcher, and there is no outside funding for this study.

CONFIDENTIALITY

All of the information you contribute to this study will be maintained electronically through the Qualtrics software system. All of your responses will be copied without any identification to a file used to conduct statistical analyses. The principal investigator (Katharine Lindberg), her supervisor (Joseph Miller), and research assistants on the study will be the only people with access to the data you provide (other than possible Institutional Review Board auditors at the University of North Dakota at some point in the future). Your signed consent form and answers will be deleted no sooner than September 1, 2019. You will not be personally identified in any reports or publications that may result from this study.

IS THIS STUDY VOLUNTARY?

Your participation is voluntary. You may choose not to participate or you may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled. If you choose to withdraw without completing the protocol, you are still entitled to receive the course credit agreed to for your participation. We do hope, of course, that you appreciate the value and importance of your candid answers to this survey.

CONTACTS AND QUESTIONS

The principal investigator on this study is Katharine Lindberg, who is a master's student in the Clinical Psychology program at the University of North Dakota (katharine.lindberg@und.edu). She is supervised by Dr. Joseph Miller, full professor in the Psychology Department at the University of North Dakota (701-777-4472 or joseph.miller@email.und.edu).

If you have questions regarding your rights as a research participant, or if you have any concerns or complaints about the research, you may contact the University of North Dakota Institutional Review Board at (701) 777-4279. Please call this number if you cannot reach the researcher, or if you wish to talk to someone else about the study.

You are highly encouraged to print a copy of this form for future reference.

I have read and understood the research project explained above. Anything that wasn't clear to me was explained so I could understand it. If I have any other questions later, I can have these answered, too. I understand that I don't have to help with the project and can discontinue participation at any time throughout the study without penalty. I wish to take part in this study.

Appendix B
Demographic Questionnaire

In this section, you will complete a number of questions relating to yourself, including your background, relevant diagnoses, impairments, etc. Please complete all the following questions to the best of your knowledge.

1. Email Address.
   Ø (enter)

2. Gender
   Ø Male
   Ø Female
   Ø Unknown
   Ø Unspecified

3. Age
   Ø (enter)

4. What is your ethnicity?
   Ø Hispanic or Latino
   Ø Not Hispanic or Latino
   Ø Unknown

5. What is your race?
   Ø American Indian or Alaska Native
   Ø Asian
   Ø Black or African American
   Ø Native Hawaiian or Other Pacific Islander
   Ø White
   Ø Other (enter)
   Ø Unknown

6. Please estimate your family's annual income.
   Ø Less than $10,000
   Ø $10,000 - $19,999
   Ø $20,000 - $29,999
   Ø $30,000 - $39,999
   Ø $40,000 - $49,999
   Ø $50,000 - $59,999
   Ø $60,000 - $69,999
   Ø $70,000 - $79,999
   Ø $80,000 - $89,999

- Ø $90,000 - $99,999
- Ø $100,000 - $119,999
- Ø $120,000-$139,999
- Ø $140,000-$159,999
- Ø $160,000-$179,999
- Ø $180,000-$199,999
- Ø Greater than $200,000

7. Indicate the highest level of education you have achieved:
    - Ø Less than HS Diploma or GED
        - Ø If less than a HS Diploma or GED, number of years of school completed: (enter)
    - Ø GED/High-School Diploma Equivalent
    - Ø High School Diploma
    - Ø Less than a 2 or 4 year college degree
        - Ø If less than a 2- or 4- year degree, indicated number of years of college completed: (enter)
    - Ø Associates (2-year) Degree
    - Ø Bachelor's (4-year) Degree
    - Ø Less than a Master's Degree
        - Ø If less than a Master's Degree, indicate years of graduate training post-bachelors: (enter)
    - Ø Master's Degree
    - Ø Less than a Doctoral Degree
        - Ø If less than a Doctoral Degree, indicate number of years of post-Masters training: (enter)
    - Ø Doctoral Degree

8. Are you currently in school?
    - Ø Yes
        - Ø What is your overall GPA? (enter)
    - Ø No
        - Ø What was the last GPA you achieved? (enter)

9. Do you speak any languages other than English?
    - Ø Yes
        - Ø If yes, what other language(s) do you speak? (enter)
        - Ø Which of these languages are you fluent in? (enter)
    - Ø No

10. Is English your first language?
    - Ø Yes
    - Ø No

11. Have you been tested by a Psychologist in the past six months?
    - Ø No
    - Ø Yes
        - Ø If yes (tested by a Psychologist in past six months), what for? (enter)

12. Were you born prematurely?
    - Ø Yes
        - Ø If yes (born prematurely), how old were you at delivery? (enter)
    - Ø No

13. Please indicate whether you have been diagnosed with any of the following:
    - Ø Attention Deficit/Hyperactivity Disorder
    - Ø Learning Disorder/Disability
    - Ø Mood Disorder/Depression
    - Ø Anxiety Disorder
    - Ø Obsessive-Compulsive Disorder (OCD)
    - Ø Panic Attacks
    - Ø Asperger's
    - Ø Autism Spectrum Disorder
    - Ø Pervasive Developmental Disorder
    - Ø Oppositional Defiant Disorder
    - Ø Conduct Disorder
    - Ø Diabetes
    - Ø Lupus
    - Ø Seizure Disorder
    - Ø Neuropathy
    - Ø Multiple Sclerosis (MS)
    - Ø Brain Tumor
    - Ø Stroke/CVA
    - Ø Traumatic Brain Injury (TBI)/Concussion

14. Have you ever suffered a serious fall where you hit your head?
    - Ø Yes
    - Ø No

15. Have you ever been in a motor vehicle accident?
    - Ø Yes
    - Ø No

16. Have you ever been knocked unconscious?
    - Ø Yes
        - Ø If yes (knocked unconscious), how long ago did this occur (Please try to indicate months or years). (enter)

- Ø If yes (knocked unconscious), please select all that occurred as a result of this.
    - Ø Memory Loss
    - Ø Hospitalization
    - Ø Attention Difficulties
    - Ø Other (enter)
- Ø No

17. Do you have a visual impairment?
- Ø Yes
  - Ø If yes (visual impairment), is the impairment correctable with glasses/contacts?
    - Ø Yes
    - Ø No
- Ø No

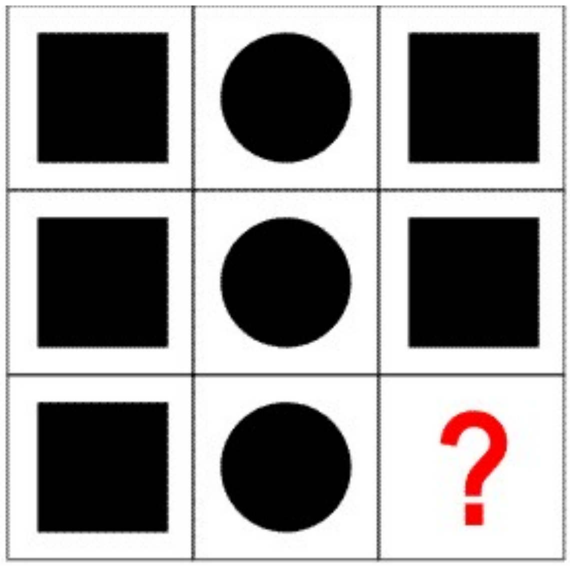
18. Do you have any physical or motor disabilities/problems?
- Ø Yes
  - Ø If yes (physical/motor problems), please describe. (enter)
- Ø No

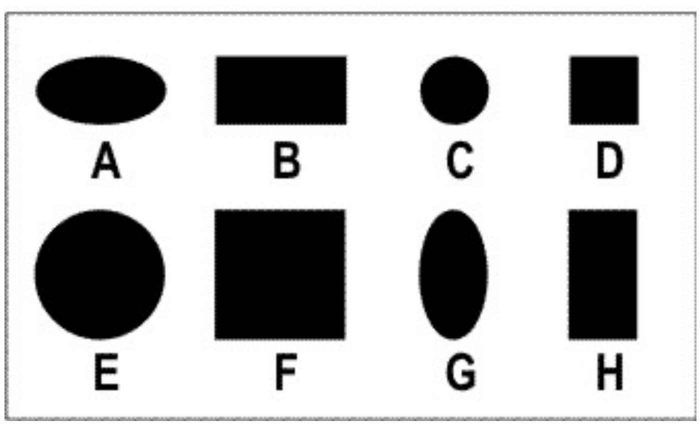
Appendix C

Experimental Inductive Matrix Reasoning Task Directions and Example Presentation

In this section, you will look at matrix test items. After looking at each matrix item, you are to select the answer option (Labeled A, B, C, D, E, F, G, or H) which best fits into the space marked with a question mark. The correct answer should work going **both across the rows and down the columns**. Please respond as accurately as possible.

All matrix items were presented to participants as such:





Appendix D
Catalog of All Experimental Inductive Matrix Reasoning Task Items

Item #	Feature 1 Rules		Feature 2 Rules		Specific Presentation Set Items (Feature 1/Feature 2)		
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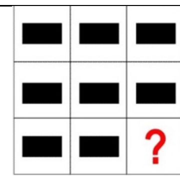
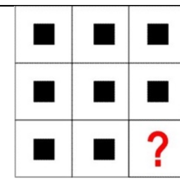
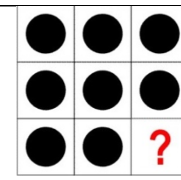
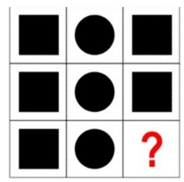
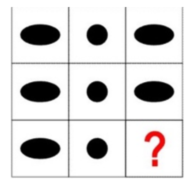
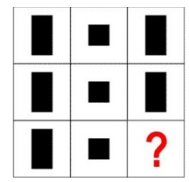
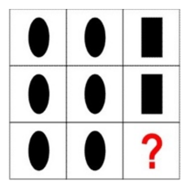
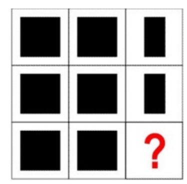
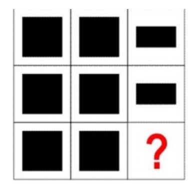
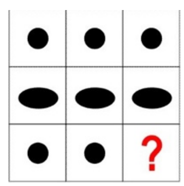
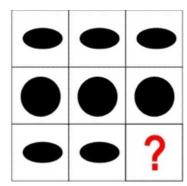
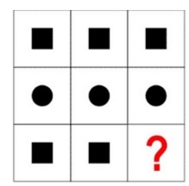
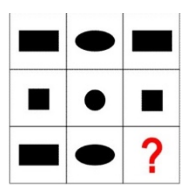
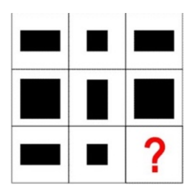
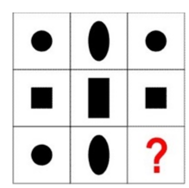
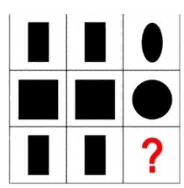
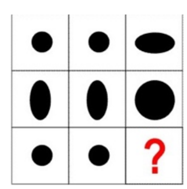
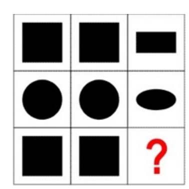
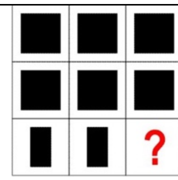
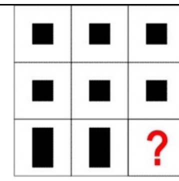
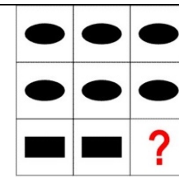
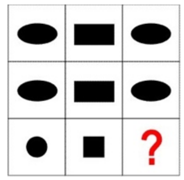
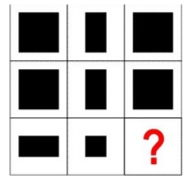
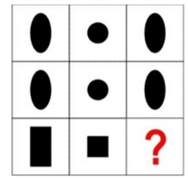
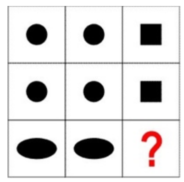
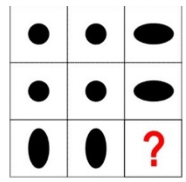
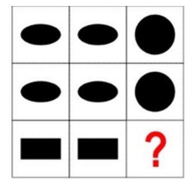
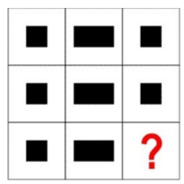
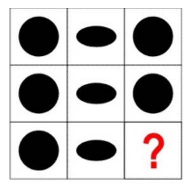
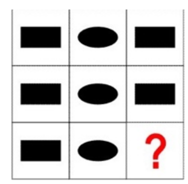
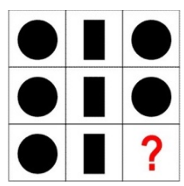
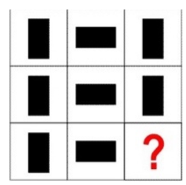
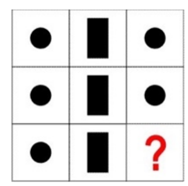
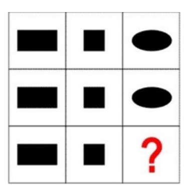
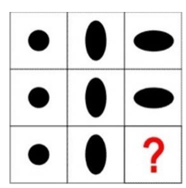
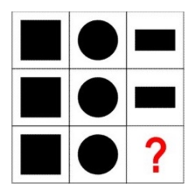
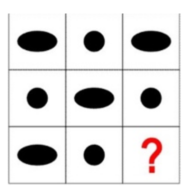
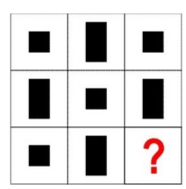
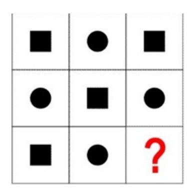
1	SAME	SAME	SAME	SAME			
2	SYM	SAME	SAME	SAME			
3	2/3	SAME	SAME	SAME			
4	SAME	SAME	SAME	SYM			
5	SYM	SAME	SAME	SYM			
6	2/3	SAME	SAME	SYM			

	Feature 1 Rules		Feature 2 Rules		Specific Presentation Set Items (Feature 1/Feature 2)		
Item #	Rows	Columns	Rows	Columns	Shape/Width	Width/Height	Height/Shape
7	SAME	SAME	SAME	2/3			
8	SYM	SAME	SAME	2/3			
9	2/3	SAME	SAME	2/3			
10	SAME	SAME	SYM	SAME			
11	SYM	SAME	SYM	SAME			
12	2/3	SAME	SYM	SAME			
13	SAME	SAME	SYM	SYM			

Item #	Feature 1 Rules		Feature 2 Rules		Specific Presentation Set Items (Feature 1/Feature 2)		
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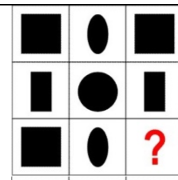
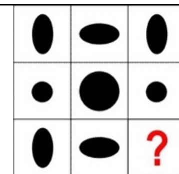
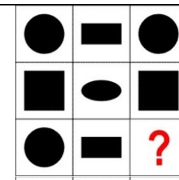
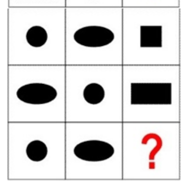
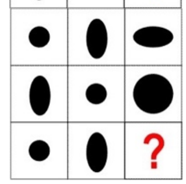
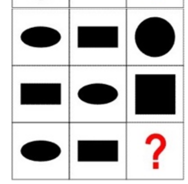
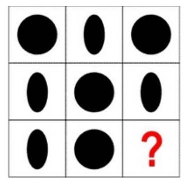
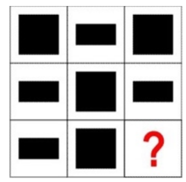
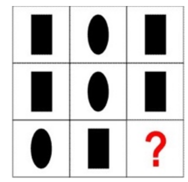
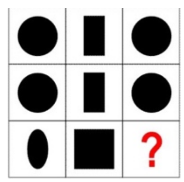
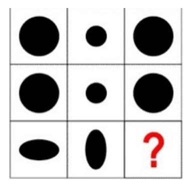
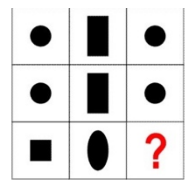
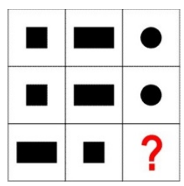
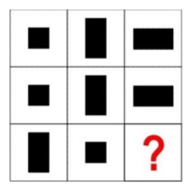
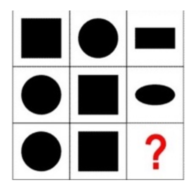
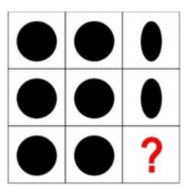
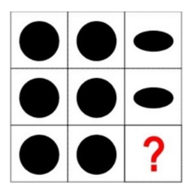
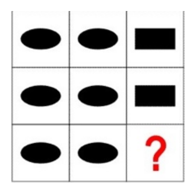
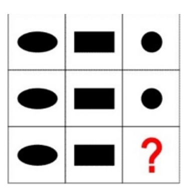
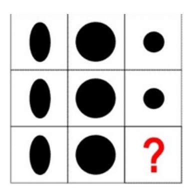
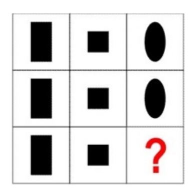
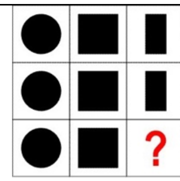
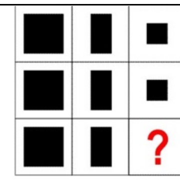
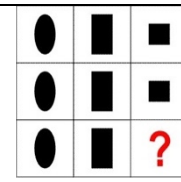
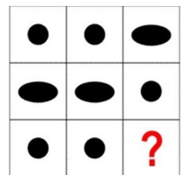
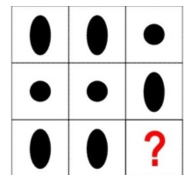
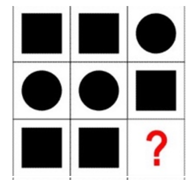
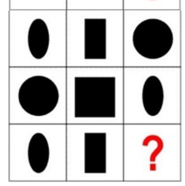
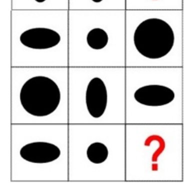
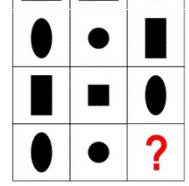
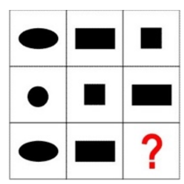
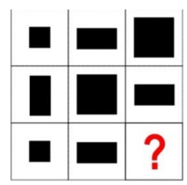
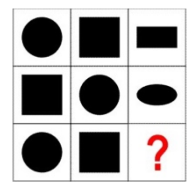
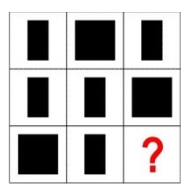
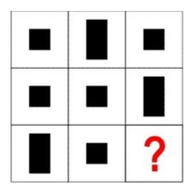
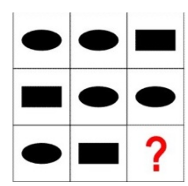
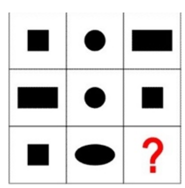
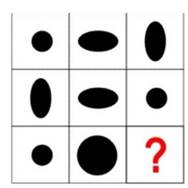
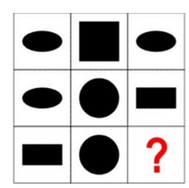
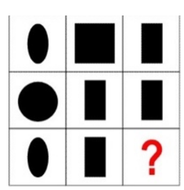
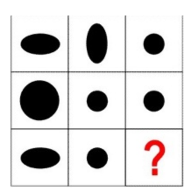
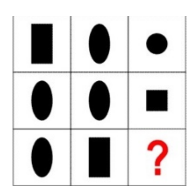
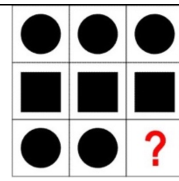
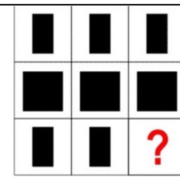
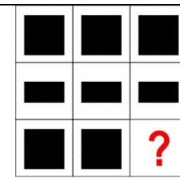
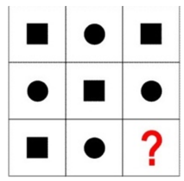
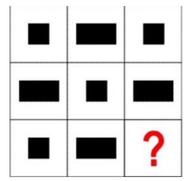
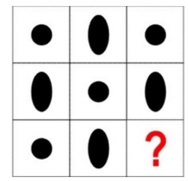
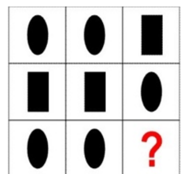
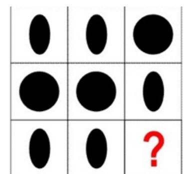
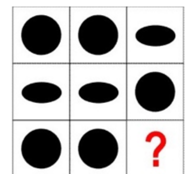
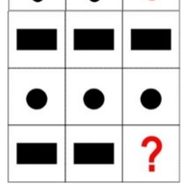
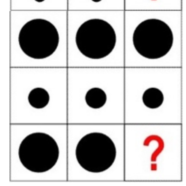
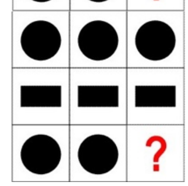
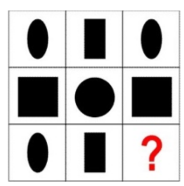
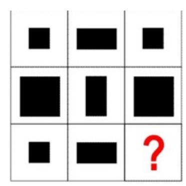
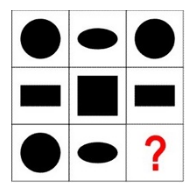
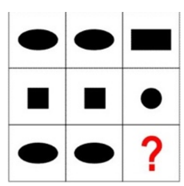
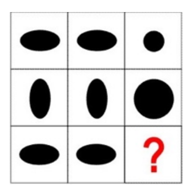
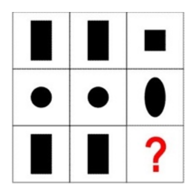
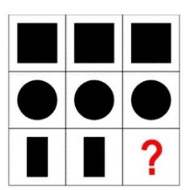
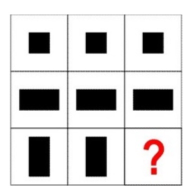
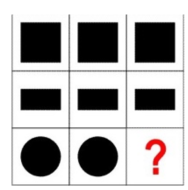
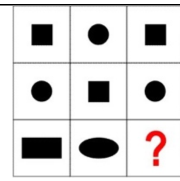
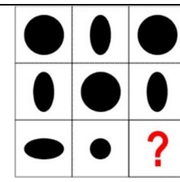
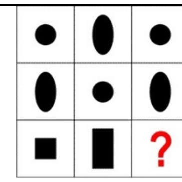
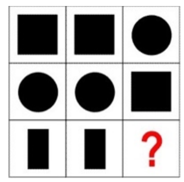
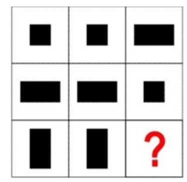
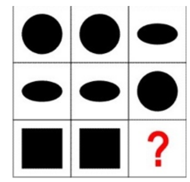
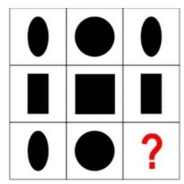
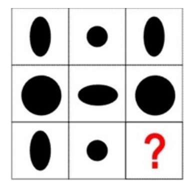
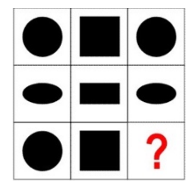
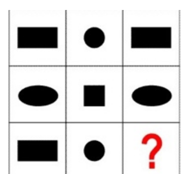
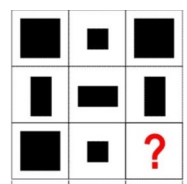
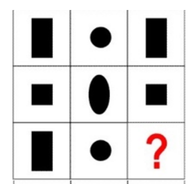
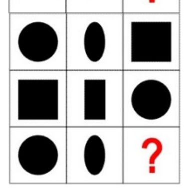
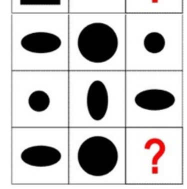
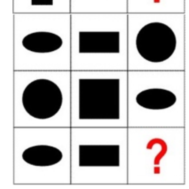
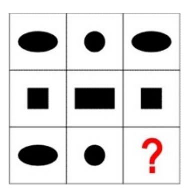
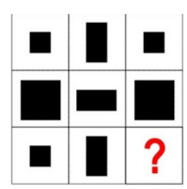
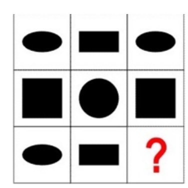
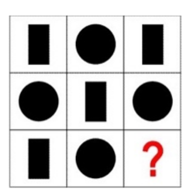
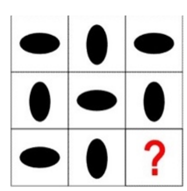
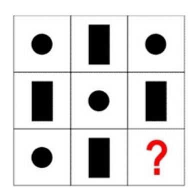
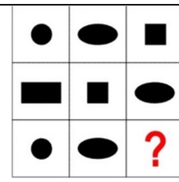
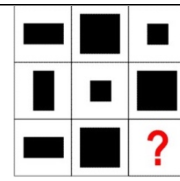
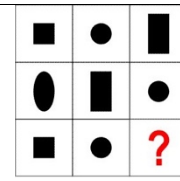
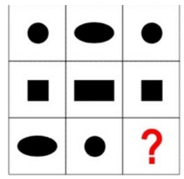
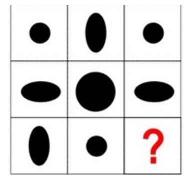
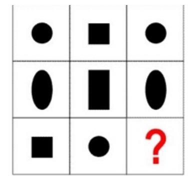
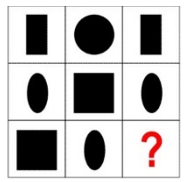
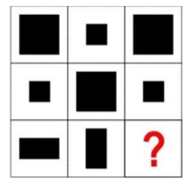
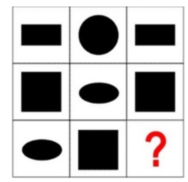
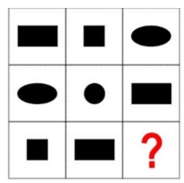
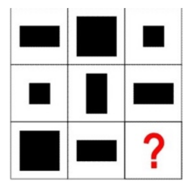
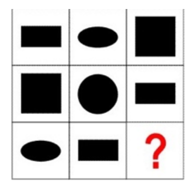
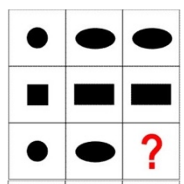
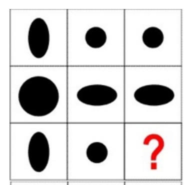
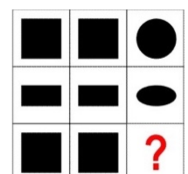
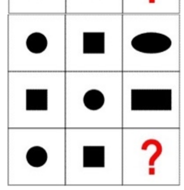
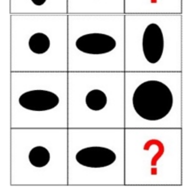
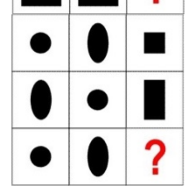
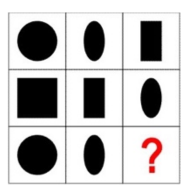
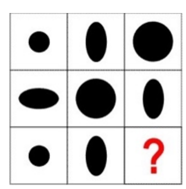
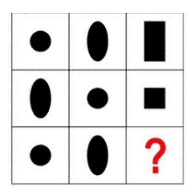
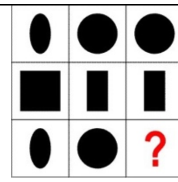
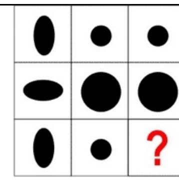
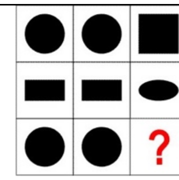
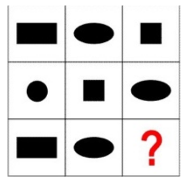
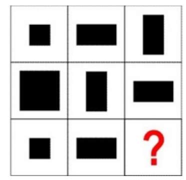
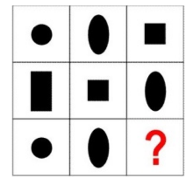
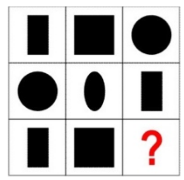
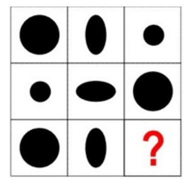
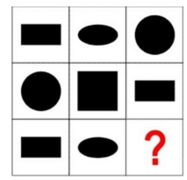
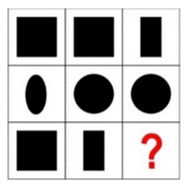
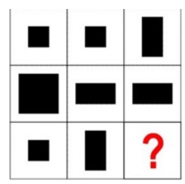
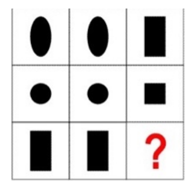
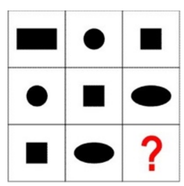
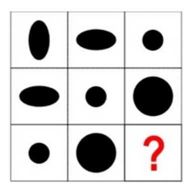
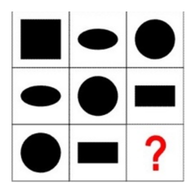
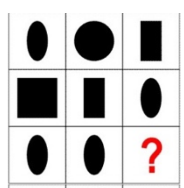
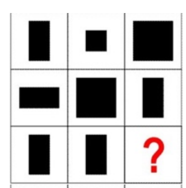
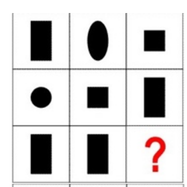
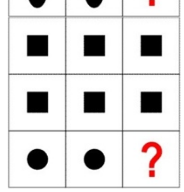
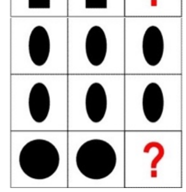
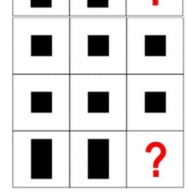
14	SYM	SAME	SYM	SYM			
15	2/3	SAME	SYM	SYM			
16	SAME	SAME	SYM	2/3			
17	SYM	SAME	SYM	2/3			
18	2/3	SAME	SYM	2/3			
19	SAME	SAME	2/3	SAME			
20	SYM	SAME	2/3	SAME			

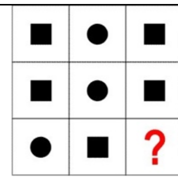
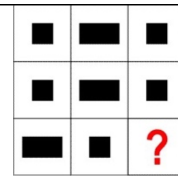
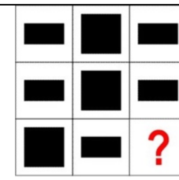
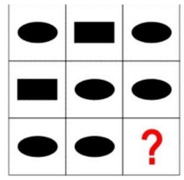
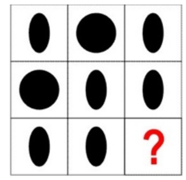
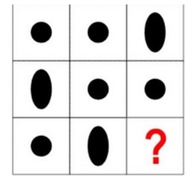
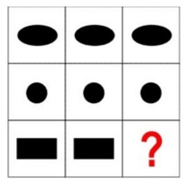
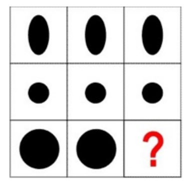
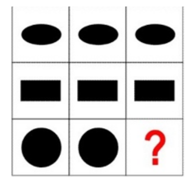
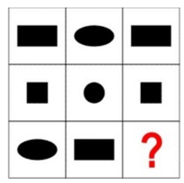
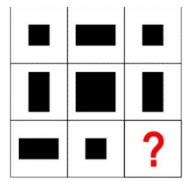
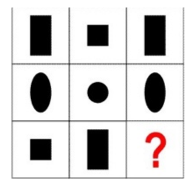
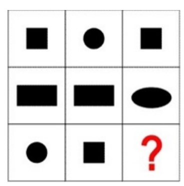
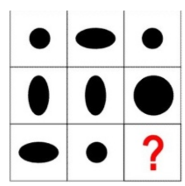
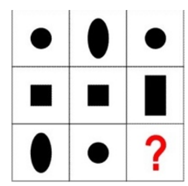
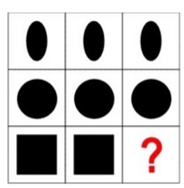
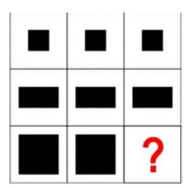
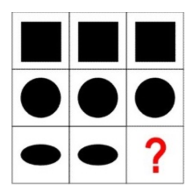
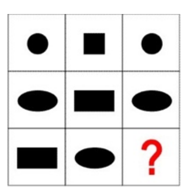
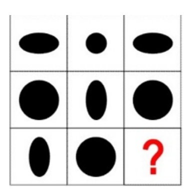
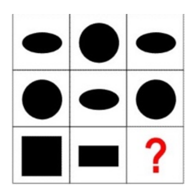
	Feature 1 Rules		Feature 2 Rules		Specific Presentation Set Items (Feature 1/Feature 2)		
Item #	Rows	Columns	Rows	Columns	Shape/Width	Width/Height	Height/Shape
21	2/3	SAME	2/3	SAME			
22	SAME	SAME	2/3	SYM			
23	SYM	SAME	2/3	SYM			
24	2/3	SAME	2/3	SYM			
25	SAME	SAME	2/3	2/3			
26	SYM	SAME	2/3	2/3			
27	2/3	SAME	2/3	2/3			

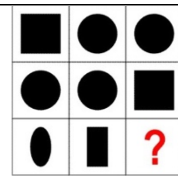
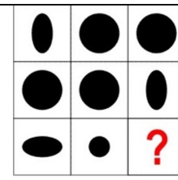
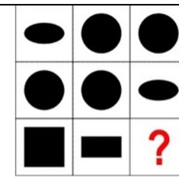
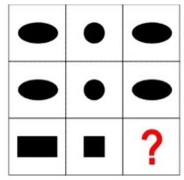
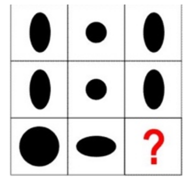
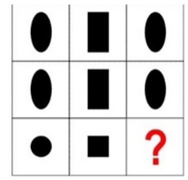
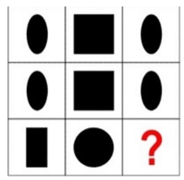
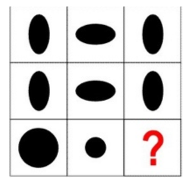
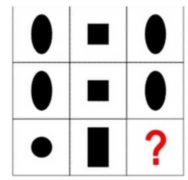
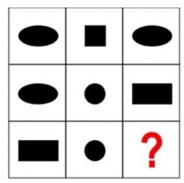
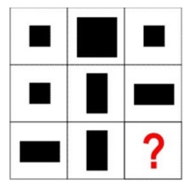
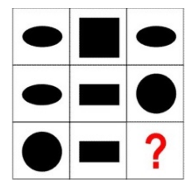
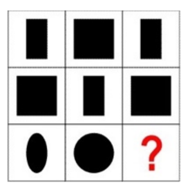
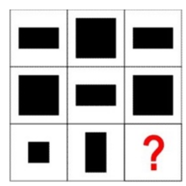
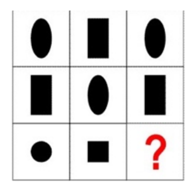
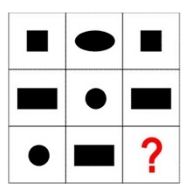
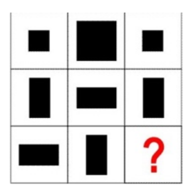
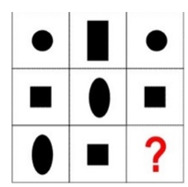
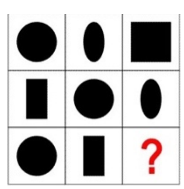
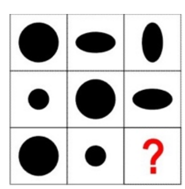
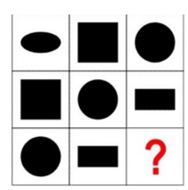
Item #	Feature 1 Rules: Rows	Feature 1 Rules: Columns	Feature 2 Rules: Rows	Feature 2 Rules: Columns	Specific Presentation Set Items (Feature 1/Feature 2): Shape/Width	Width/Height	Height/Shape
28	SAME	SYM	SAME	SAME			
29	SYM	SYM	SAME	SAME			
30	2/3	SYM	SAME	SAME			
31	SAME	SYM	SAME	SYM			
32	SYM	SYM	SAME	SYM			
33	2/3	SYM	SAME	SYM			
34	SAME	SYM	SAME	2/3			

Item #	Feature 1 Rules: Rows	Feature 1 Rules: Columns	Feature 2 Rules: Rows	Feature 2 Rules: Columns	Specific Presentation Set Items (Feature 1/Feature 2): Shape/Width	Width/Height	Height/Shape
35	SYM	SYM	SAME	2/3			
36	2/3	SYM	SAME	2/3			
37	SAME	SYM	SYM	SAME			
38	SYM	SYM	SYM	SAME			
39	2/3	SYM	SYM	SAME			
40	SAME	SYM	SYM	SYM			
41	SYM	SYM	SYM	SYM			

Item #	Feature 1 Rules		Feature 2 Rules		Specific Presentation Set Items (Feature 1/Feature 2)		
	Rows	Columns	Rows	Columns	Shape/Width	Width/Height	Height/Shape
42	2/3	SYM	SYM	SYM			
43	SAME	SYM	SYM	2/3			
44	SYM	SYM	SYM	2/3			
45	2/3	SYM	SYM	2/3			
46	SAME	SYM	2/3	SAME			
47	SYM	SYM	2/3	SAME			
48	2/3	SYM	2/3	SAME			

Item #	Feature 1 Rules: Rows	Feature 1 Rules: Columns	Feature 2 Rules: Rows	Feature 2 Rules: Columns	Specific Presentation Set Items (Feature 1/Feature 2): Shape/Width	Width/Height	Height/Shape
49	SAME	SYM	2/3	SYM			
50	SYM	SYM	2/3	SYM			
51	2/3	SYM	2/3	SYM			
52	SAME	SYM	2/3	2/3			
53	SYM	SYM	2/3	2/3			
54	2/3	SYM	2/3	2/3			
55	SAME	2/3	SAME	SAME			

Item #	Feature 1 Rules		Feature 2 Rules		Specific Presentation Set Items (Feature 1/Feature 2)		
	Rows	Columns	Rows	Columns	Shape/Width	Width/Height	Height/Shape
56	SYM	2/3	SAME	SAME			
57	2/3	2/3	SAME	SAME			
58	SAME	2/3	SAME	SYM			
59	SYM	2/3	SAME	SYM			
60	2/3	2/3	SAME	SYM			
61	SAME	2/3	SAME	2/3			
62	SYM	2/3	SAME	2/3			

Item #	Feature 1 Rules		Feature 2 Rules		Specific Presentation Set Items (Feature 1/Feature 2)		
	Rows	Columns	Rows	Columns	Shape/Width	Width/Height	Height/Shape
63	2/3	2/3	SAME	2/3			
64	SAME	2/3	SYM	SAME			
65	SYM	2/3	SYM	SAME			
66	2/3	2/3	SYM	SAME			
67	SAME	2/3	SYM	SYM			
68	SYM	2/3	SYM	SYM			
69	2/3	2/3	SYM	SYM			

Item #	Feature 1 Rules		Feature 2 Rules		Specific Presentation Set Items (Feature 1/Feature 2)		
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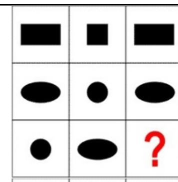
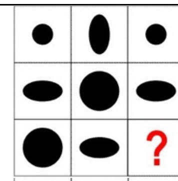
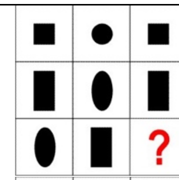
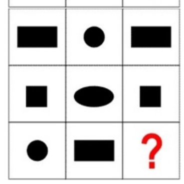
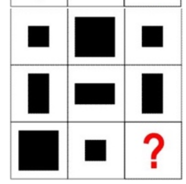
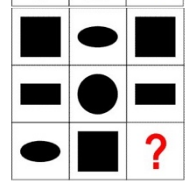
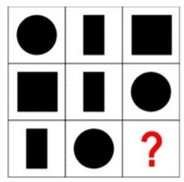
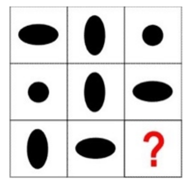
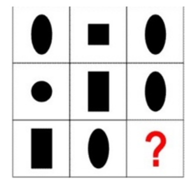
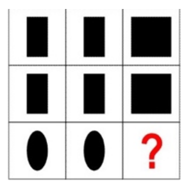
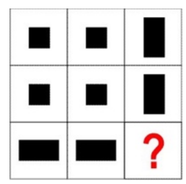
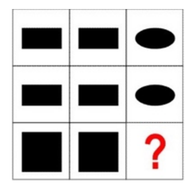
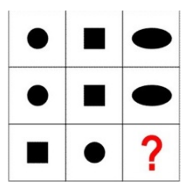
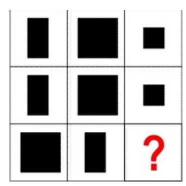
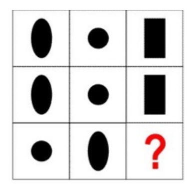
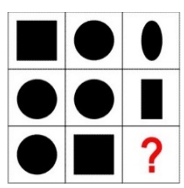
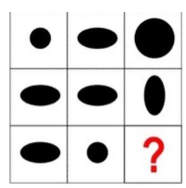
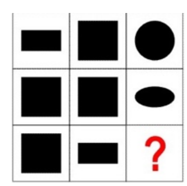
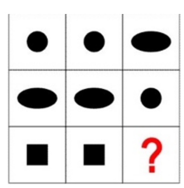
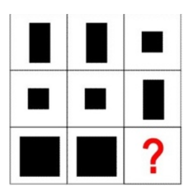
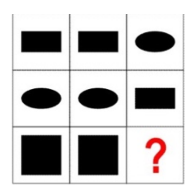
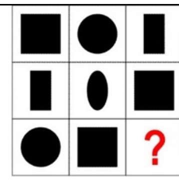
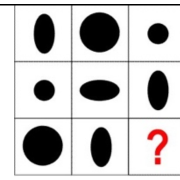
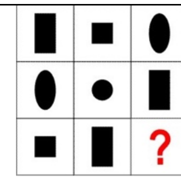
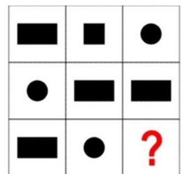
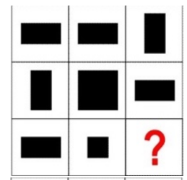
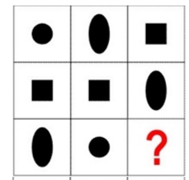
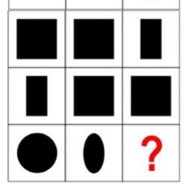
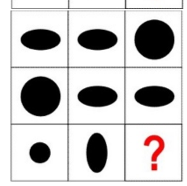
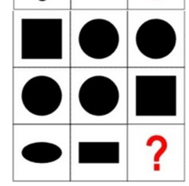
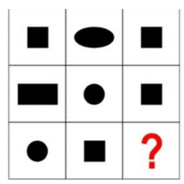
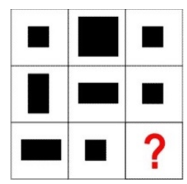
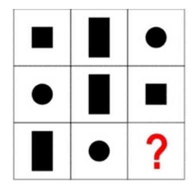
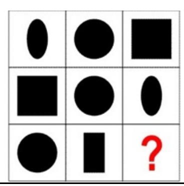
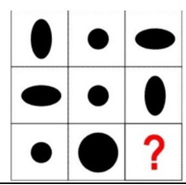
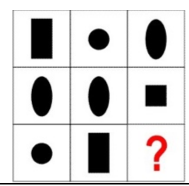
70	SAME	2/3	SYM	2/3			
71	SYM	2/3	SYM	2/3			
72	2/3	2/3	SYM	2/3			
73	SAME	2/3	2/3	SAME			
74	SYM	2/3	2/3	SAME			
75	2/3	2/3	2/3	SAME			
76	SAME	2/3	2/3	SYM			

Item #	Feature 1 Rules: Rows	Feature 1 Rules: Columns	Feature 2 Rules: Rows	Feature 2 Rules: Columns	Specific Presentation Set Items (Feature 1/Feature 2): Shape/Width	Width/Height	Height/Shape
77	SYM	2/3	2/3	SYM			
78	2/3	2/3	2/3	SYM			
79	SAME	2/3	2/3	2/3			
80	SYM	2/3	2/3	2/3			
81	2/3	2/3	2/3	2/3			

REFERENCES

Alderton, D.L., & Larson, G.E. (1990). Dimensionality of Raven's Advanced Progressive Matrices items. *Educational and Psychological Measurement, 50,* 887-900.

Anagnostouli, M., Christidi, F., Zalonis, I., Nikolaou, C., Lyrakos, D., Triantafyllou, N., Evdokimidis, I., & Kilidireas, C. (2015). Clinical and cognitive implications of cerebrospinal fluid oligoclonal bands in multiple sclerosis patients. *Neurol Sci, 36,* 2053-2060.

Carpenter, P., Just, M., & Shell, P. (1990). What one intelligence test measures: A theoretical account of the processing in the Raven's Progressive Matrices test. *Psychological Review, 97*, 404-431.

Carroll, J. B. (1993). *Human cognitive abilities: A survey of factor-analytic studies*. Cambridge University Press.

Cohen, J. (1992). A power primer. *Psychological bulletin*, *112*(1), 155.

Downey, L., Lomas, J., Billings, C., Hansen, K., & Stough, C. (2014). Scholastic success: Fluid intelligence, personality, and emotional intelligence. *Canadian Journal of School Psychology, 29*(1), 40-53.

Fraser, S. (Ed.). (1995). *The bell curve wars: Race, intelligence and the future of America*. New York: Basic Books.

Gardner, H. (1983). *Frames of* Mind*.* New York: Basic Book Inc.

Goleman, D. (1995). *Emotional Intelligence: Why it can matter more than IQ*. New York: Bantam Books.

Greenspan, S. & Driscoll, J. (1997). The role of intelligence in a broad model of personal competence. In D. Flanagan, J. Genschaft, & P. Harrison (Eds.), *Contemporary intellectual assessment*. NY: The Guilford Press.

Guthrie, R.V. (1998). *Even the rat was white: A historical view of psychology* (2nd ed.). Boston: Allyn & Bacon.

Harrison, T.L., Shipstead, Z., & Engle, R.W. (2015). Why is working memory capacity related to matrix reasoning tasks? *Mem Cogn, 43,* 389-396.

Herrnstein, R. J., & Murray, C. (1994). *The bell curve: Intelligence and class structure in American life*. New York: Simon & Schuster

Horn, J. & Noll, J. (1998). Human cognitive capabilities: Gf-Gc Theory. In D. Flanagan, J. Genschaft, & P. Harrison (Eds.), *Contemporary intellectual assessment*. NY: The Guilford Press.

Jensen, A.R. & Inouye, A.R. (1980). Level I and level II abilities in Asian, White, and Black children. *Intelligence, 4*, 41-49.

Jia, X., Liang, P., Shi, L., Wang, D., & Li, K. (2015). Prefrontal and parietal activity is modulated by the rule complexity of inductive reasoning and can be predicted by a cognitive model. *Neuropsychologia, 66*, 67-74.

Kyllonen, P. C., & Christal, R. E. (1990). Reasoning ability is (little more than) working-memory capacity? *Intelligence*, *14*(4), 389-433.

Levy, N. & Levy, J. (1989). *Mechanical aptitude and spatial relations tests*. New York: Simon & Schuster, Inc.

Lezak, M. D. (2004). *Neuropsychological assessment*. Oxford University Press, USA.

Liang, P., Jia, X., Taatgen, N.A., Zhong, N., & Li, K. (2014). Different strategies in solving series completion inductive reasoning problems: An fMRI and computational study. *International Journal of Psychophysiology, 93,* 253-260.

Lidz, C. (1997). Dynamic assessment approaches. In D. Flanagan, J. Genschaft, & P. Harrison (Eds.), *Contemporary intellectual assessment*. NY: The Guilford Press.

McGrew, K. S. (1997). Analysis of the major intelligence batteries according to a proposed comprehensive Gf-Gc framework.

McGrew, K., & Flanagan, D. (1998). *The intelligence test desk reference (ITDR): Gf-Gc cross-battery assessment*. Boston: Allyn & Bacon.

McLaurin, W. & Farrar, W. (1973). Validities of the progressive matrices tests against IQ and grade point average. *Psychological Reports, 32*(3), 803-806.

Meo, M., Roberts, M.J., & Marucci, F.S. (2007). Element salience as a predictor of item difficulty for Raven's Progressive Matrices. *Intelligence, 35,* 359-368.

Mertler, C.A., & Vannatta, R.A. (2010). *Advanced and Multivariate Statistical Methods: Practical application and interpretation, Fourth Edition.* USA: Pyrczak Publishing.

Miller, J.C., Ruthig, J.C., Bradley, A.R., Wise, R.A., Pederson, H.A., & Ellison, J.M. (2009). Learning effects in the block design task: A stimulus parameter-based approach. *Psychological Assessment, 21*(4), 570-577.

Mills, C.J., Ablard, K.E., & Brody, L.E. (1993). The Raven's Progressive Matrices: Its usefulness for identifying gifted/talented students. *Roeper Review, 15,* 183-186.

Pomerantz, J., & Lockhead, G. (1991). Perception of structure: An overview. In G. R. Lockhead and J. R. Pomerantz (Eds.), *The Perception of Structure* (pp. 1-20). Washington, DC: The American Psychological Association.

Primi, R. (2001). Complexity of geometric inductive reasoning tasks: Contribution to the understanding of fluid intelligence. *Intelligence, 30*, 41-70.

Raven, J., Raven, J. C., & Court, J. H. (1998, updated 2003). *Manual for Raven's Progressive Matrices and Vocabulary Scales*. Section 1: General Overview. San Antonio, TX: Harcourt Assessment.

Rushton, J., Skuy, M., & Bons, T. (2004). Construct validity of Raven's Advanced Progressive Matrices for African and non-African engineering students in South Africa. *International Journal of Selection and Assessment, 12,* 220-229.

Smolen, T., & Chuderski, A. (2015). The quadratic relationship between difficulty of intelligence test items and their correlations with working memory. *Frontiers in Psychology, 6,* 1270.

Spearman, C. (1904). " General Intelligence," objectively determined and measured. *The American Journal of Psychology*, *15*(2), 201-292.

Sternberg, R. (1997). The concept of intelligence and its role in lifelong learning and success. *American Psychologist, 52* (10), 1030-1037.

Stevenson, C., Alberto, R., van den Boom, M., & de Boeck, P. (2014). Visual relations children find easy and difficult to process in figural analogies. *Frontiers in Psychology, 5,* 1-9.

Vodegel Matzen, L. B. L., Van der Molen, M. W., & Dudink, A. C. M. (1994). Error analysis of Raven test performance. *Personality and Individual Differences, 16,* 433-445.

Wechsler D. Wechsler Adult Intelligence Scale–Fourth Edition. Pearson; San Antonio, TX: 2008

Wechsler, D. (2014a). *Wechsler Intelligence Scale for Children* (5th ed.). San Antonio, TX: NCS Pearson.

Wiley, J., Jarosz, A. F., Cushen, P. J., & Colflesh, G. H. (2011). New rule use drives the relation between working memory capacity and Raven's Advanced Progressive Matrices. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37*, 256–263.

Yuan, Z., Qin, W., Wang, D., Jiang, T., Zhang, Y., & Yu, C. (2012). The salience network contributes to an individual's fluid reasoning capacity. *Behavioral Brain Research, 229,* 384-390.