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Signatures of multiple processes contributing to fluid reasoning performance

Ehsan Shokri-Kojori[a,*], Daniel C. Krawczyk[a,b]

[a] Center for BrainHealth®, School of Behavioral and Brain Sciences, The University of Texas at Dallas, Dallas, TX, USA
[b] Department of Psychiatry, University of Texas Southwestern Medical Center, Dallas, TX, USA

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ABSTRACT

We aimed to achieve a better understanding of the cognitive processes of fluid reasoning (or fluid intelligence; Gf), the ability to reason in novel conditions. While fluid reasoning has often been considered a unitary construct, multiple cognitive processes are expected to affect fluid reasoning performance. Yet, the contribution of various cognitive processes in fluid reasoning performance remains under-explored. We hypothesized that individual differences in fluid intelligence can be viewed as a composite of individual differences in performance in various processes of Gf. Change detection, rule verification, and rule generation were the three processes-of-interest that were additively recruited in a novel visuospatial reasoning task. We observed decreases in accuracy and increases in response time as the processing requirements increased across task conditions. Hierarchical multiple linear regression analyses showed that individual differences in the likelihood of success and speed of each of these processes, accounted for different aspects of individual differences in accuracy and response time in fluid reasoning performance, as measured by Raven's Progressive Matrices. Change detection was a significant contributor to performance in problems with higher visuospatial demand, however, rule verification and rule generation consistently contributed to performance for all problem types. Our findings support the position that individual differences in fluid intelligence emerge as a composite of performance on separable cognitive operations, with rule processing being important for differentiating performance on high difficulty problems.

1. Introduction

Fluid reasoning (or fluid intelligence; Gf) is an important cognitive construct as it correlates well with a broad range of cognitive abilities (Marshalek, Lohman, & Snow, 1983; Salthouse, 2004) and predicts life outcomes such as socioeconomic status and academic performance (Strenze, 2007). Analyses of the relationship between the factors representing different cognitive domains and the general intelligence factor (g; Spearman, 1904), shows that the reasoning domain has the highest correlation with g (Deary, Penke, & Johnson, 2010; Salthouse, 2004). These observations suggest that fluid reasoning is highly associated with a common aspect of performance variability between individuals (as represented by g) in many cognitive domains. Accordingly, fluid reasoning appears to represent a collection of processes that are common to a wide range of cognitive domains, specifically those that emphasize controlled processing (Salthouse, 2005). Standardized tests such as Raven's Progressive Matrices (RPM; Raven, Court, & Raven, 1988) have been successful in a variety of demographic groups to study individual differences in fluid reasoning (Deary, Whalley, & Crawford, 2004; Herrnstein & Murray, 1994).

When fluid reasoning is considered as a *multi-process* cognitive construct, the contributions of the underlying processes to the individual differences in performance remain unclear. To test the multi-process theoretical framework, we hypothesized that the contribution of the multiple processes should emerge as distinct contributions to (between-subject) variance in *each* of accuracy and response time measures of performance of Gf. In contrast to the multi-process framework, these hypothesized sub-processes of Gf may not rely on different underlying substrates, thus the performance on sub-processes will not account for distinct aspects of performance variance in Gf.

1.1. *Measuring fluid reasoning*

Tasks that are effective in revealing individual differences are important for identifying the cognitive processes involved in fluid reasoning. RPM, Cattell Culture Fair IQ (Intelligent Quotient) test (Cattell, 1949), and Wechsler Adult Intelligence Scale (WAIS; Wechsler, 1958), are three prominent examples of tasks that provide standardized measurements of Gf. Tasks that assess Gf present items that are novel in structure and stimulus presentation. These tasks are less likely to be experienced in everyday life, and performance is not expected to differ among demographic groups (Kaufman & Kaufman, 1993). In addition

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[*] Corresponding author.
E-mail address: ehsan.shokrikojori@nih.gov (E. Shokri-Kojori).

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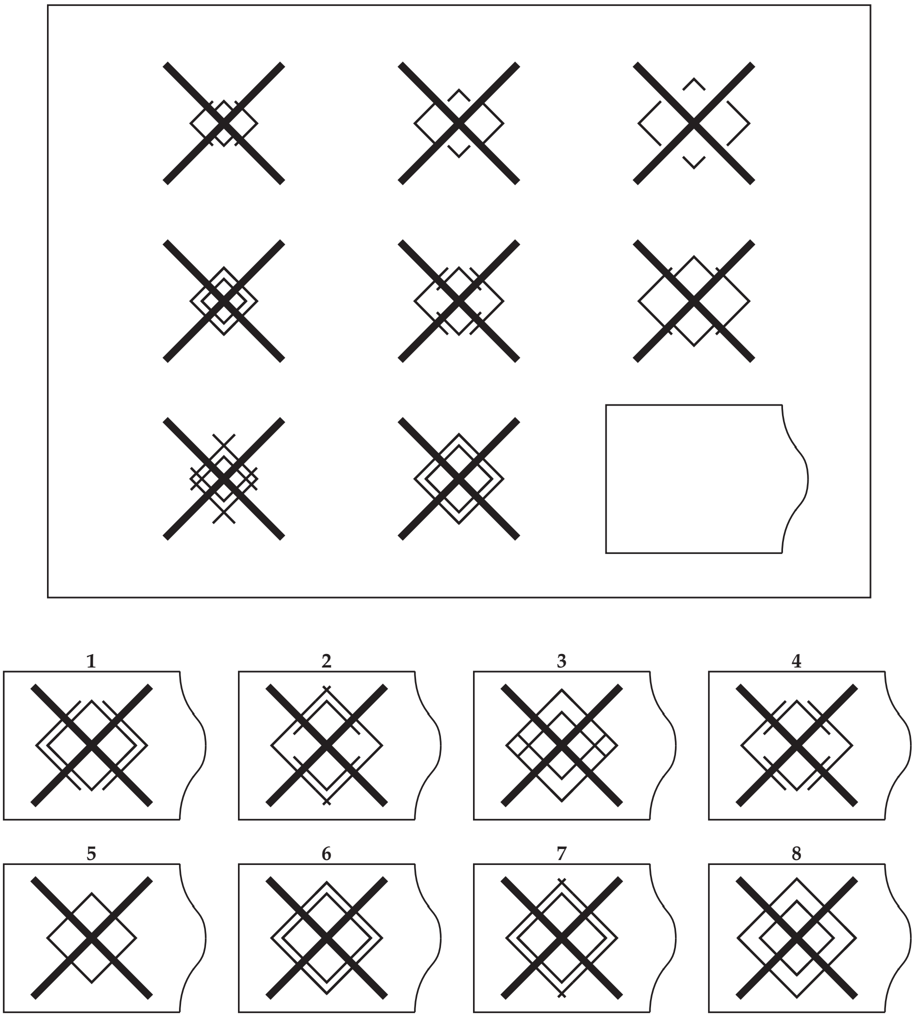

Fig. 1. A visuospatial reasoning problem resembling items presented in the RPM task. Solutions to such problems involve tracking changes across rows and columns to isolate and select the abstract shape that fits all possible dimensions of change.

to verbal, numerical, and letter-based paradigms (Ekstrom, French, Harman, & Dermen, 1976; Zachary, 1986), most of the tasks used to assess Gf are reasoning paradigms defined using visuospatial stimuli (Ekstrom et al., 1976; Salthouse, Pink, & Tucker-Drob, 2008).

In some matrix-style visuospatial reasoning tasks, each item contains several shapes shown in a composition (e.g., a two-dimensional matrix). Shapes are arranged or modified in a progressive way to cue a rule (or several rules). A rule can be viewed as a consistent association or pattern between elements of stimuli (e.g., shape features). Rules can also consist of a set of relational changes among stimuli. Consistent with the identified rule (or rules), an answer choice must be selected that best completes the shapes (Fig. 1).

The nonverbal property of visuospatial reasoning tasks minimizes the need for language processing in solving the items and is particularly useful for testing children and older adults (Domino & Domino, 2006). Moreover, the items are designed to be culturally unbiased, making them applicable to testing individual differences in fluid reasoning across a broad range of demographic groups (Park & Minear, 2004). Finally, the visuospatial nature of the problems provides numerous ways to modulate item difficulty and influence performance in a variety of ways. For example, an item can be perceptually difficult due to challenges associated with finding relevant features. Alternatively, an item may be challenging due to difficulty in finding a rule (or a set of rules) that applies to the identified features.

1.2. *Raven's progressive matrices (RPM)*

RPM is a visuospatial reasoning task that provides a reliable measurement of fluid reasoning ability, Gf (Snow & Lohman, 1984). RPM problems are simple in structure and require minimal instructions. In most sets, an item includes a matrix of shapes with a single shape missing in the bottom-right corner (Fig. 1). To choose the correct response, the participant examines the relationship(s) between shapes in the matrix and decides which answer choice best completes the matrix. RPM tasks are often not timed, and the proportion of the correct items is used to calculate the final score for an individual.

In the current study, we used Advanced Progressive Matrices (APM) set-I (S1) and the abridged version of APM set II (APM-SII): APM short set II (APM-SSII; Arthur Jr. and Day (1994)), to assess fluid reasoning abilities in young adults (Raven et al., 1988). Advantages of using APM-SI and APM-SSII, each with 12 items (against using the original APM-SII with 36 items), included achieving comparable administration times on all tasks used in our study. Many studies have shown that performance on RPM is highly correlated with performance on a wide range of task domains and complexity levels, particularly those that represent the Gf domain (Colman, 1990; Salthouse et al., 2008). Some have suggested that the RPM is a “paradigmatic” index of Gf (Mackintosh, 1998). Yet, the contributions of specific fluid reasoning processes to RPM item difficulty and individual differences in fluid reasoning abilities have not been fully identified.