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Beyond the intellect: Complexity and learning trajectories in Raven's Progressive Matrices depend on self-regulatory processes and conative dispositions

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ABSTRACT

The Raven's Progressive Matrices (RPM) test entails a 40-min contextualized interaction with a set of progressively difficult cognitive activities. Item-to-item experiences accumulate to total scores determined by, and reflective of, cognitive abilities. The current research is interested in what happens during those 40 min. Personality (Openness, Extraversion and Neuroticism) and metacognitive factors have consistently been associated, albeit at low levels, with performance. 252 industry managers completed, inter alia, the RPM either with or without confidence ratings. Using multi-level modeling and controlling for general ability, we investigate whether a) experiential factors emerge in individual performance trajectories, b) whether trajectories are associated with cognitive and personality factors, and c) whether requirements to externalize metacognitive reflection (provide confidence ratings) links to performance. Results suggest that metacognitive reflection impeded performance; that learning trajectories are separable from performance trajectories; and that trajectories are statistically moderated, most notably by Neuroticism, over and above cognitive ability. Modeling item-level responses following experimental manipulations that serve as a catalyst for modifying cognition-personality relations, provides an important avenue for integrating experimental and differential methods. Psychometric complexity (ψ_C) and psychometric learning (ψ_L) are proposed as theoretically derived empirical bases to ground investigations of statistical moderation. Together they may provide a bridge to causal accounts of the divide between intelligence and personality.

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1. Introduction

The Raven's Progressive Matrices (RPM) is a widely known group-administered test of general fluid intelligence (*Gf*). In a standard administration of Set II of the advanced RPM, 36 progressively more complex items are presented within a time limit of 40 min. As the test progresses, each successive item demands induction of different rules, multiple rules, and/or more complex instantiations of rules from earlier items (Carpenter, Just, & Shell, 1990). This test of increasingly complex items was Raven's (1941) operationalization of intelligence as the capacity to perceive relations and educe correlates (Spearman, 1927). From a test-taker's perspective, the RPM is a more or less idiosyncratic experience with distinct, challenging cognitive activities lasting over a period of up to 40 min. Adopting a multi-level approach, the current research is interested in modeling the moderation of a broad range of between-person differences on within-person performance trajectories spanning that 40 min.

As the basis of this, we note that modern conceptualizations of intelligence, cognitive ability, and reasoning as they are realized in everyday experiences, warrant greater attention toward non-cognitive influences (Ackerman, 1988; Sitzmann & Ely, 2011). A range of personality and metacognitive factors has consistently been observed to be associated with intellectual performance (Bandura, 1991; Soubelet & Salthouse, 2011), although the strengths of those associations tend to be rather small for all but a few of these factors. The goal of the current work is to map the influence of personality and metacognitive reflection, not simply on total RPM scores, but also on item-to-item performance trajectories. For reasons to be presented, we focus on Openness, Extraversion, and Neuroticism as moderating personality facets, and metacognitive reflection as operationalized by the requirement to provide item-specific confidence ratings.

The research presented here aims to make a number of important contributions. First, it extends investigations of the cognition-

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personality links to include item-by-item RPM performance trajectories. Second, it investigates whether being required to externalize metacognitive reflection has an impact on RPM performance. Third, building on Schweizer and colleagues fixed-link SEM models (e.g., Ren, Goldhammer, Moosbrugger, & Schweizer, 2012; Schweizer, 2006), which distinguish item-difficulty from item-position effects, it introduces a theory-driven conceptualization of statistical moderation of performance trajectories. Finally, the research benefits from sampling experienced business managers and exposing them to ecologically valid assessment conditions that matter to the individual. We begin by outlining the rationale for the type of statistical moderation we investigate.

1.1. Conceptualizing moderators of RPM performance: psychometric complexity

Conceptually, the capacity to learn and to deal with novelty (Crawford, 1991; Sternberg, 1985; Sternberg & Gastel, 1989) and complexity (Marshalek, Lohman, & Snow, 1983; Stankov, 2000) have been regarded as reflecting elementary reasoning abilities central to *Gf* (Carpenter et al., 1990; Primi, 2001). At a task level, increasing novelty or complexity should therefore result in greater demand being placed on *Gf* resources, and hence concomitantly, be associated with a monotonic increase in the correlation between task performance and measures of *Gf* (Stankov & Crawford, 1993). Birney and Bowman (2009) differentiated process-oriented *psychometric complexity* factors from other factors that make solutions difficult but do not necessarily place higher demands on *Gf* (and thus do not result in changes of *Gf*-performance correlations). They investigated *Gf* processes by experimentally manipulating relational processing demands of reasoning tasks (Birney, Halford, & Andrews, 2006; Halford, Wilson, & Phillips, 1998), with the expectation that this would result in a *psychometric complexity effect* – that is, an increase in the correlation between task performance and independent measures of *Gf* as complexity of the items increased. Although relational reasoning overall was correlated with *Gf*, Birney and Bowman found *Gf* better differentiated test takers' capacity to maintain information across multiple steps within an item (i.e., serial processing demand), rather than relational complexity differences between-items. That the psychometric complexity effect was present only as a function of within-problem WM demand is broadly consistent with Engle and colleagues who argue that the pervasive correlation between WM and *Gf* is driven by the capacity for *controlled attention* (e.g., Engle, Tuholski, Laughlin, & Conway, 1999; Kane, Hambrick, & Conway, 2005).

In asking the question of whether the observed progression of RPM item difficulty is a function of a psychometric complexity effect or some other difficulty factor, we need to consider the processes involved. Prima facie, two cognitive factors are most prominent, reasoning and learning. The RPM requires an individual to determine the answer to a particular problem by inductive reasoning with a relatively small set of rules (Carpenter et al., 1990). Although some authors have suggested that learning does not occur in tasks like the RPM (Alderton & Larson, 1990; Sternberg, 2002), others have presented evidence that individuals show learning effects after both retesting (Bors & Vigneau, 2001) and within a single administration (Bui & Birney, 2014; Verguts & De Boeck, 2002). Verguts and De Boeck found that when solving RPM items, participants tended to use rules that they had previously encountered in the test, thus implying at least some learning. Ren, Wang, Altmeyer, and Schweizer (2014), using fixed-link SEM models (Schweizer, 2006), separated out learning processes from performance (i.e., reasoning) processes in the RPM, showing that item-order has a significant association with performance and that this item-to-item learning process accounted for a substantial proportion of the remaining systematic variance in RPM scores after item-difficulty (reasoning) had been considered.

In essence, and challenging common uni-dimensionality assumptions (Birney & Sternberg, 2006), these are two factors that reliably capture individual differences in RPM performance, but do so, we suggest, by acting across different levels of the test. The first, uncontroversial factor is an ability factor (*Gf* in this case) that is stable within an individual but differs between individuals. The second factor is an experiential factor associated with change as one progresses through the test. This second factor may still be *Gf*, albeit instantiated differently, but it may also be something qualitatively distinct, for instance, attention (Ren et al., 2012) or even impulsivity (Lozano, 2015; Ren, Gong, Chu, & Wang, 2017). In either case, it is a within-person factor operating at, or more accurately, emerging across, items.

Following the goal of Ren et al. (2014), we aim to separate the role of learning from performance within RPM, but do so using a multi-level modeling (MLM) approach (rather than SEM) and with a broad array of cognitive and personality moderators in a sample of high-functioning working adults. First, controlling for item-to-item experience (i.e., item-order), we conceptualize *psychometric complexity* (ψ_C) as a statistical moderation of the cognitive demand of items on performance trajectories (what Ren et al., 2012, refer to as the ability-specific component of fluid reasoning). Second, controlling for item-to-item difficulty, we conceptualize *psychometric learning* (ψ_L) as a statistical moderation of item experience on performance trajectories (Ren et al. refer to this as the position-specific component of fluid reasoning). In the following sections we explicate potential personality and metacognitive moderators of these relationships.

1.2. Broader determinants of RPM performance: cognition-personality links and self-regulation

Beyond cognitive ability, RPM performance trajectories can be characterized by both task-relevant factors (e.g., emerging knowledge of rules) and task-irrelevant factors (e.g., evolving confidence in one's capacity to perform). Task-relevant learning is germane and intrinsically connected to performance (Sweller, Van Merriënboer, & Paas, 1998), and task-relevant reflection on reasoning is typically considered to facilitate this (Mitchum, Kelley, & Fox, 2016). On the other hand, task-irrelevant learning and task-irrelevant, or self-reflection introduce extraneous factors that may negatively impact performance through influencing metacognitive processes that drive motivation, engagement, effort and sensitivity to changing task demands (e.g. Bouffard, Boisvert, Vezeau, & Larouche, 1995; Heslin, Latham, & Vandewalle, 2005; Pintrich, 2000). Some of these factors are associated with stable personality traits that have been directly linked with cognitive abilities. We consider these cognition-personality links now.

1.2.1. Personality and cognitive ability

In a large sample of 2317, Soubelet and Salthouse (2011) investigated cognition-personality relations as a function of specific cognitive abilities (*Gf*, *Gc*, Memory and Speed) and age (18–96). Focusing here on *Gf*, the highest observed association, as indicated by standardized regression coefficients, was with Openness/Intellect (~0.40). The remaining associations were considerably smaller. The associations with Extraversion, Neuroticism, and less reliably, Agreeableness, were statistically significant at around −0.20, −0.15, and −0.10 (respectively). Conscientiousness <−0.10 was not associated with *Gf*. These are remarkably consistent with findings from an earlier meta-analysis by Ackerman and Heggestad (1997).

There have been numerous attempts to provide causal explanations for the cognition-personality links (Ackerman, 1996; Cattell, 1987; Zimprich, Allemand, & Dellenbach, 2009). As they have been found to be reliably associated with cognitive performance, we focus on Openness, Extraversion and Neuroticism, because these three personality factors are most reliably associated with cognitive performance.

Openness/Intellect: Investment of cognitive resources in learning and problem-solving requires facilitating personality traits, dispositions, and

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