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## Personality differences in cognitive control? BAS, processing efficiency, and the prefrontal cortex

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Emotion and cognition can be viewed as complementary behavioral control systems, both of which show considerable variation across individuals. We tested the hypothesis that affective individual differences in behavioral activation (i.e., approach tendencies) are related to individual differences in cognitive control functions of the prefrontal cortex (loosely, executive function). Our guiding intuition was that individual differences in reward responsiveness might be related to differences in goal-directed (reward seeking) cognitive control processes. Working memory tasks can greatly tax cognitive control, and specific areas within the prefrontal cortex (PFC) are known to be sensitive to working memory load.

Behavioral studies have shown that extraverts can have slightly better working memory performance than introverts (Humphreys & Revelle, 1984; Lieberman & Rosenthal, 2001). Given our theoretical interest in reward responsiveness, which is similar but not necessarily identical to extraversion, we first replicated this finding using measures of Behavioral Activation Sensitivity (BAS) (Carver & White, 1994). Consistent with prior work on extraversion, higher BAS predicted slightly better working memory performance the first time participants performed a challenging working memory task, the 3-back task (in which participants see items, such as a words or faces, displayed every few seconds on a computer screen, and have to indicate whether a current item exactly matches the one they saw three items previously). The task places high demands on cognitive control by requiring participants to actively maintain information (e.g., a word) in the face of distraction (two intervening words), and then respond on the basis of that information. However, with repeated administration of the task, this effect reversed leading to no main effect of BAS on performance but a strong interaction of BAS with time (task repetition). In hindsight

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this interaction with time could partially reflect a waning of task engagement for high BAS individuals.

On the basis of the relationships between working memory and PFC and working memory and BAS, we predicted that BAS would correlate negatively with neural activity in PFC as participants were engaged in working memory. We expected a negative association because higher BAS has been associated with better performance in previous work. That is, when performance is equated, the same task should result in a lower working memory load for individuals who are more efficient.

In two functional MRI studies (Burgess, Gray, & Braver, 2003; Gray & Braver, 2002), we measured brain activity during a 3-back working memory task. As predicted, higher BAS was associated with lower working memory-related activity in specific areas within PFC that are known to be related to cognitive load or mental effort (anterior cingulate, left lateral PFC). This result held regardless of the testing session. This is important because it suggests that high BAS individuals have greater processing efficiency, in the sense articulated by Eysenck and Calvo (1992) for anxiety. That is, taking all six task repetitions into account, while there was not a main effect of BAS on task performance, there was a theoretically meaningful main effect of BAS on brain activity that was fully compatible with an extension of the processing efficiency argument (Gray & Braver, 2002). High BAS individuals showed less activation than low BAS individuals, despite performing equally well. This suggests that high BAS individuals performed the task more efficiently. We were able to identify specific trials within the 3-back task that placed high demands on control (similar intervening items lead to high interference) and some that placed relatively low demands (unrelated intervening items lead to low interference). Intriguingly, the same difference in activation held despite the strong difference in the demand for control.

The data suggest that some component of the cognitive control network depends on BAS in a true functional sense, albeit the relation is complex. In addition, the data illustrate that fMRI can be used to shed light on questions traditionally of interest to personality psychologists.

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