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Original and revised reinforcement sensitivity theory in the prediction of executive functioning: A test of relationships between dual systems

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ABSTRACT

Executive functioning relates to cognitive processes that are effortful and controlled, whereas processes underlying personality are assumed to be routine and automatic (Elliot & Thrash, 2002, 2010). We evaluated potential influences between these dual systems by examining the link between executive functioning and biologically based personality measures associated with original reinforcement sensitivity theory (o-RST) and revised reinforcement sensitivity theory (r-RST). Results showed that flight (a tendency to commit to poorly planned, escape behavior) negatively predicted executive functioning. We find partial support for the general hypothesis of links between the dual systems. Generally, r-RST was a better predictor of executive functioning than o-RST. The proposed structure of the r-RST measurement model was confirmed.

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1. Introduction

Executive functions are neurocognitive processes of the frontal cortex that maintain an appropriate problem solving mindset concerned with future goal attainment (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Underlying cognitive processes involve working memory, inhibition and planning, understanding space and time, selective inhibition, response preparation, goal formation tendencies, and adaptability (e.g., Suchy, 2009). Poor executive functioning is associated with deficits in goal formation tendencies, reduced capacity for self-control, emotional lability, flattened affect, irritability, impulsivity, carelessness, rigidity, and difficulty in shifting attention. Executive functions are thought of as being "effortful" and "controlled." In contrast, neurocognitive processes underlying biologically based personality scales of temperament such as Gray's (1970) original Reinforcement Sensitivity Theory (o-RST) and Gray and McNaughton's (2000) revised Reinforcement Sensitivity Theory (r-RST) are often thought of as being "routine" and "automatic" (e.g., Cury, Elliot, Fonseca, & Moller, 2006; Elliot & Thrash, 2002, 2010; Gray, 1970; Gray & McNaughton, 2000; Jackson, 2008a, 2011).

Relationships between RST variables and executive functions would be interesting to identify since they would provide further evidence for the general neurocognitive architecture of the type proposed by the dual systems models of Elliot and Thrash (2002, 2010) and Jackson (2008a, 2011). In these dual system models, automatic and routine processes are honed by effortful and controlled processes to produce effective and functional behavior. Elliot and Thrash (2002, p. 806) argue that goal orientations are channels through which biological drives are directed, such that biological drives are energizers whereas goal orientations are specific, cognitive forms of self regulation that provide focus and direction. Elliot and Thrash (2002, 2010) and Jackson (2008a, 2011) maintain that relationships between these dual systems provide the theoretical basis for more informed models of personality compared with those derived from exploratory factor analysis. We choose RST and executive functioning because they typify these two contrasting neurocognitive processes as opposed to other processes (such as positive and negative affect) which are less easy to define in these terms.

Empirical evidence in favor of dual systems models is somewhat lacking. One study finds little evidence in favor of dual process theory (Gillespie, Cloninger, Heath, & Martin, 2003). The current study will add to the small literature aimed at identifying whether or not the dual systems are related as argued by Elliot and Thrash (2002, 2010) and Jackson (2008a, 2011). We test this idea using objectively measured executive functions as opposed to the self-report measures used previously.

Gray's (1970) o-RST is a theoretical model of the biological basis of personality consisting of the original Behavioral Inhibition System (or o-BIS; aligned with a mix of anxiety and fear; Jackson, 2009; Smillie, Pickering, & Jackson, 2006) and the original

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Behavioral Approach System (or o-BAS; aligned with extraversion; Smillie et al., 2006). Gray and McNaughton's (2000) r-RST consists of a Fight/Flight/Freezing system (r-FFFS, which is an avoidance system related to fear; Smillie et al., 2006), r-BIS (now a defensive approach and conflict management system related to anxiety; Smillie et al., 2006) and r-BAS (closely aligned to extraversion; Jackson, 2009; Smillie et al., 2006).

Prior to the development of r-RST (Gray & McNaughton, 2000), the avoidance system of o-RST was generally associated with the neuroticism/anxiety cluster of traits found in the Five Factor Model, the Giant Three and the o-BIS. This is important because neuroticism has been associated with poorer executive functioning such as impaired response selection (i.e. conflict detection/resolution, error monitoring) in tasks such as the Stroop test (e.g., Luu, Collins, & Tucker, 2000). This suggests:

Hypothesis 1. o-BIS will be negatively related to executive functioning performance.

In r-RST, the avoidance system broadly consists of r-FFFS associated with fear, and r-BIS associated with anxiety. Gray and McNaughton (2000) argued that the r-FFFS mediates escape from aversive stimuli (r-Flight), submission (r-Freezing), and vociferous defensive aggression (r-Fight); the latter possibly also being partially interpretable as an approach behavior since defensive aggression involves attacking the fear-inducing stimulus (for examples see Jackson, 2009). How fear relates to executive functioning is not well known (Rothbart, Ellis, & Posner, 2004), but using general principles of resource allocation theory (e.g., Kanfer & Ackerman, 1989; Norman & Bobrow, 1975), we think it is likely to severely inhibit executive functioning by curtailing cognitive resources to maximize the success of a fast and furious fight or escape response. This suggests:

Hypothesis 2. The cluster of traits associated with r-FFFS will be negatively related to executive functioning performance.

The difference between Hypothesis 1 and Hypothesis 2 lies at the core of how r-RST and o-RST are different from each other and how fear is different from anxiety. One example demonstrates how differential evidence in favour or against Hypothesis 1 and Hypothesis 2 will affect the literature in an important way. Time estimation plays a key role in efficient performance of many daily activities and is an executive function since effective timing is implied by effective executive functioning and problems with time estimations are observed in clinical groups with executive dysfunction (e.g., Barkley, 1997). There is a strong literature indicating that strong emotions (often referred to as high fear and high anxiety) are related to overestimates of time (e.g., Lake & LaBar, 2011); by measuring fear and anxiety separately, this study determines which are related to executive functions.

Both o-BAS (Gray, 1970) and r-BAS (Gray & McNaughton, 2000) are highly related to reward sensitivity (Smillie et al., 2006). There is evidence that the approach system may differentially influence different executive functions. Greater neural efficiency during working memory tasks has been observed in individuals with higher self-reported o-BAS (Gray et al., 2005). Moreover, high reward sensitivity is related to faster reversal learning (Gullo, Jackson, & Dawe, 2010) and adult extraverts appear to have better working memory performance than introverts (Lieberman & Rosenthal, 2001). In contrast, in studies of children, high o-BAS has been associated with poorer executive functioning (Blair, Peters, & Granger, 2004). This also seems reasonable since deficits in executive functioning are likely related to impulsiveness and impulsiveness is related to o-BAS (Gray, 1970). Although the evidence is not strong given possible opposite effects, the possibility of greater neural efficiency in reward sensitive individuals suggests:

Hypothesis 3. Approach tendencies (o-BAS, r-BAS) will be positively related to executive functioning performance.

In summary, our research determines how o-RST and r-RST are related to executive functioning with the aim of testing the dual system model of personality.

2. Method

2.1. Participants

Participants were 336 Australian full-time workers (mean age = 39.08 years, range 18 to 69 years, *SD* = 13.16; male: 56%; female 44%) who were recruited from a Sydney-based website offering people willing to engage in research. The highest education of participants was: school, 31.4%; trade, 17.3%; undergraduate degree, 35.7%; masters degree, 13.4%, PhD, 2.1%). Seniority of participants in the workplace was: staff, 39.8%; junior manager, 28.5%; senior manager, 31.7%.

2.2. Procedure and measures

Participants completed a battery of objective tests of executive functioning and personality questionnaires that were modules of the YWeDo online cognitive laboratory (Jackson, 2010) located at www.YWeDo.com/lab.asp. Participants were paid for their contribution. Fraser and Boag (2010) compared tests administered using the YWeDo online laboratory with paper-based tests and reported few differences. The study was approved by the UNSW ethics committee and participants provided informed consent.

2.3. Measures of executive function

2.3.1. Color Stroop

The color Stroop involves presentation of names of colors presented in different colored text (e.g., the word "green" presented as green text or a different color such as blue text). Five different color choices are presented. Participants choose the color of the word.

The color Stroop task indexes the ability to inhibit well-learned responses as shown by the difference in reaction time to respond between the congruent condition (where the spelling matches the color) and the incongruent condition (where the spelling does not match the color). There were 20 congruent trials and 20 incongruent trials.

2.3.2. Trail making

This version of the trail making consists of 20 squares. In the congruent task, the squares are numbered 1–20, and the participant clicks on each square in ascending numerical order. In the incongruent task, the squares consist of numbers (1–10) or letters (A–J) and the participant clicks squares in ascending order alternating between the numbers and letters (i.e., 1-A-2-B-3-C, etc.).

The difference in time between the two tasks is a measure of interference control and a measure of executive functioning. Errors must be corrected before continuing and add to the completion time.

2.3.3. Time estimation

Time perception is often thought of as an executive function (e.g., Barkley, 1997). In this study two online time estimation tasks were conducted:

2.3.4. Estimated time to complete an action

Participants answered the following Time to do questions developed by Jackson (2008b). How many minutes would you estimate that it takes you to do the following if you did them at a steady pace and if you were in good health: (1) make a cup of coffee if all the ingredients are in front of you and you have to boil a full kettle of water? (2) peel five large apples? (3) drink a litre of water and eat two large peeled apples (or similar)? (4) read a five page short story of 2000 easy words? (5) walk round five buses which are all parked together lengthwise (i.e. front to back)? (6) empty a standard sized watering can by sprinkling water over a flower bed? (7) complete 5 mazes? (8) make an average sized double bed (2 sheets and 2 blankets)? (9) answer 200 easy questions in a survey? Items are standardized before summing. Longer estimates are associated with ineffective executive functioning because it suggests inefficiency and lack of focus.

2.3.5. Time Estimation Task

The Time Estimation Task uses a prospective paradigm in which participants judge known time intervals. Participants estimate time at the following intervals and in the following order (5, 10, 15, 20, 25, 30, 35, 40 s) whilst speaking out loud random numbers that are generated on the screen and presented at random time intervals. Participants press a start button clearly labeled with the time to be estimated. Once the perceived time to be estimated had passed the participant presses the button again.

The average perception of time at 5 s was 6.30 s (*SD* = 5.71); at 10 s, it was 8.86 s (*SD* = 3.25); at 15 s, it was 12.60 (*SD* = 4.41); at 20 s, it was 17.42 (*SD* = 7.24); at 25 s, it was 20.83 s (*SD* = 7.79); at 30 s it was 25.88 s (*SD* = 9.58); at 35 s, it was 29.46 s (*SD* = 11.06) and at 40 s, it was 34.98 (*SD* = 15.89). Times are standardized before summing. Quick time estimates indicate lack of restraint and therefore poor executive functioning.

2.4. Measures of personality

BIS/BAS Scales to measure o-RST (see Carver & White, 1994). The o-BAS is measured as Reward Responsiveness, Drive and Fun Seeking. An example o-BAS item: "When I get something I want I feel excited and energized." The o-BIS scale measures fear and anxiety. An example o-BIS item: "Even if something bad is about to happen to me, I rarely experience fear or nervousness." Internal reliability was o-BAS Fun seeking ($\alpha = 0.72$), o-BAS Drive ($\alpha = 0.81$), o-BAS Reward Responsiveness ($\alpha = 0.75$) and o-BIS ($\alpha = 0.76$). Items are scored on a Likert scale with 4 response categories.

Jackson 5 (J5; Jackson, 2009) measures r- RST as r-BAS, r-BIS, r-Fight scale, r-Flight and r-Freeze scales. All items are scaled on a Likert scale with5 response categories. Example items include "I like to do things which are new and different" (r-BAS), "I want to do well compared to my peers" (r-BIS), "I would fight back if someone hit me first" (r-Fight), "If approached by a suspicious stranger, I run away" (r-Flight), "If my boss told me to do two contradictory things, I would not know what to do" (r-Freeze). Internal consistency was; r-BAS ($\alpha = 0.79$), r-BIS ($\alpha = 0.76$), r-Fight ($\alpha = 0.78$), r-Flight ($\alpha = 0.77$) and r-Freezing ($\alpha = 0.72$). These alphas are similar to those reported by Jackson (2009) but a little higher than those reported by Harnett, Loxton, and Jackson (2013) and Morton and White (2013).

2.5. Analyses

After rescoring measures so that high scores reflected good executive functioning and positive relationships between personality and executive functioning reflected support for the hypotheses, we correlated our personality measures with each of the tests of executive functioning. This provided a fine detailed indication of the relationships between RST and executive functioning. We then constructed a latent variable to represent an underlying construct of executive functioning and then regressed o-RST and r-RST against the latent variable. This provided an efficient way of comparing how o-RST and r-RST predict executive functioning. When judging model fit, we applied the guidelines of Kline (2005), and Hu and Bentler (1999). Specifically, good fit was indicated by a non-significant χ^2 test, GFI/AGFI/CFI $\geqslant$ .95, and RMSEA $\leqslant$ .06. Additionally, non-nested models were compared using the AIC and BIC, whereby smaller values indicate a model is more parsimonious and better-fitting, and the R^2 statistic, whereby higher values indicate a greater proportion of variance in executive functioning is explained by the model.

3. Results

Means, standard deviations, alphas and correlations are reported in Table 1. Higher scores on the executive functioning tasks (e.g., faster Stroop, slower time estimates) were scored to indicate better executive functioning. Alphas are generally at least reasonable.

Table 1
Means, standard deviations and correlations between variables ($n = 336$).

	Mean	SD	Alpha	Fast stroop	Fast trail	Fast time to do	Slow time estimate
Executive functioning							
Fast Stroop	4.98	4.22	.94		.14**	.12*	.11*
Fast Trail	16.87	11.70	.85			−.03	.18**
Fast Time to do	.07	4.43	.56				.09
Slow Time Estimate	.03	.74	.85				
o-RST							
Low o-BIS	19.99	3.51	.76	−.00	.02	.02	−.03
o-BAS – Fun	10.69	2.49	.72	.12*	−.02	−.12*	−.01
o-BAS - Drive	11.51	2.26	.81	.05	−.00	−.08	−.07
o-BAS - Reward Responsiveness	16.26	2.35	.75	.16**	−.04	−.05	.03
r-RST							
r-BAS	22.34	3.75	.79	.08	−.03	−.06	−.01
Low r-BIS	22.07	3.71	.76	−.06	.08	.05	.03
Low r-Flight	16.60	4.53	.77	.12*	−.09	.21**	.28**
Low r-Freeze	16.93	4.17	.72	.10	−.08	.17**	.24**
r-Fight	19.27	4.29	.78	−.03	−.06	−.10	−.11

Means are reported as usually scored, but we adjusted scale directions so that high scores represent effective executive functioning and positive correlations represent support for hypotheses. Therefore for executive functions, effective executive functions are shown with the prefix Fast = fast response time or Slow = Slow response time. For personality scales, some scales are reversed (e.g., Low Neuroticism) so that a positive correlation provides support for hypotheses.

* $p < .05$.

** $p < .01$.

Table 2
Regression of personality variables against latent variable of executive functioning.

	R^2	Chi Sq	*df*	*p*	GFI	AGFI	CFI	RMSEA	AIC	BIC
o-								RST	.03	25.30
	.03	.98		.96.96	.05 69.30	70.51				
14										
r-								RST	.39	21.07
	.22	.99		.97.99	.03 77.07	78.79				
17										

o-RST represents the four variables in Carver and White (1994) model and r-RST is represented by the five variables in Jackson (2009).

Fast color Stroop and fast trail making are positively related to slow time estimates ($r = .11$, $p < .05$; $r = .18$, $p < .001$) and fast color Stroop is related to fast Time to do estimates ($r = .12$, $p < .05$). Correlations between the executive function tasks are generally significant but low. Executive functioning tasks have something in common but also tap different aspects. No evidence from the correlations is found in support of Hypothesis 1. In support of Hypothesis 2, low Flight and low Freeze from r-RST correlate positively with fast Time to do ($r = .21$, $p < .001$; $r = .17$, $p < .17$, $p < .001$) and slow time estimation ($r = .28$, $p < .001$; $r = .24$, $p < .001$), and low r-Flight also has a significantly positive correlation with fast Stroop ($r = .12$, $p < .05$). In support of Hypothesis 3, people who score highly on all o-BAS Fun and Reward Seeking scales tended to have fast Stroop ($r = .12$, $p < .05$; $r = .16$, $p < .01$). Contrary to Hypothesis 3, people high on o-BAS Fun seeking tended to report slower times on the Time to do task ($r = -.12$, $p < .05$) such that they reported they would spend more time on tasks than others.

Next, observed variables of o-RST and r-RST were regressed against a latent variable representing an overall construct of executive functioning (predicted from all the executive functions acting as observed variables). All paths between the latent variable of executive functioning and the observed variables of executive functioning provided standardized regression weights greater than .22 and all paths were significant except for one path, which was close to significance.

In the prediction of executive functioning from the four variables in o-RST, none of the o-RST variables were significant. In the prediction of executive functioning from the five variables of r-RST, only low Flight is significant ($\beta = .46$, $p < .001$) in support of Hypothesis 2. As shown by R^2 in Table 2, r-RST is more predictive than o-RST. Goodness of fit is reported in the first two rows of Table 2. Only r-RST provides non-significant chi-square, the most stringent of model fit statistics, and has the best fitting values of RMSEA. Interestingly, o-RST has better fit on AIC and BIC, reflecting its greater parsimony despite poorer prediction of Executive Functioning. Taken together, results favor the r-RST model.

Finally, we checked our model using latent variable modelling similarly to Jackson (2009). As shown in Fig. 1, this provided the opportunity of introducing a latent variable of r-FFFS and to check Jackson's (2009) model of r-RST. We noticed a slight improvement through cross loading Item 27 (“I avoid work that makes me look bad”) on r-FFFS as well as r-BIS, and through adding a link from r-Fight to r-BAS (see Jackson, 2009; Smillie et al., 2006). Similarly to Jackson (2009), sex was used to improve the relationship between r-Fight and r-FFFS. As shown in Fig. 1, low r-FFFS remained associated with effective executive functioning across all models. Goodness of fit is shown in Table 3. There is a small improvement in fit as each of these improvements in the model is introduced.

4. Discussion

In support of Hypothesis 2, results show that executive functioning is inversely predicted by Jackson's (2009) r-Flight scale from r-RST such that flight is associated with reduced executive functioning. Overall, r-RST provided the best fit to the data, accounting for more than ten times the variance in executive functioning compared to o-RST. Flight is fast, action-oriented escape from threat in which “slow” cognitive executive functioning strategies are likely “short circuited” and more faster, immediate reactions are given priority. We interpret our results using

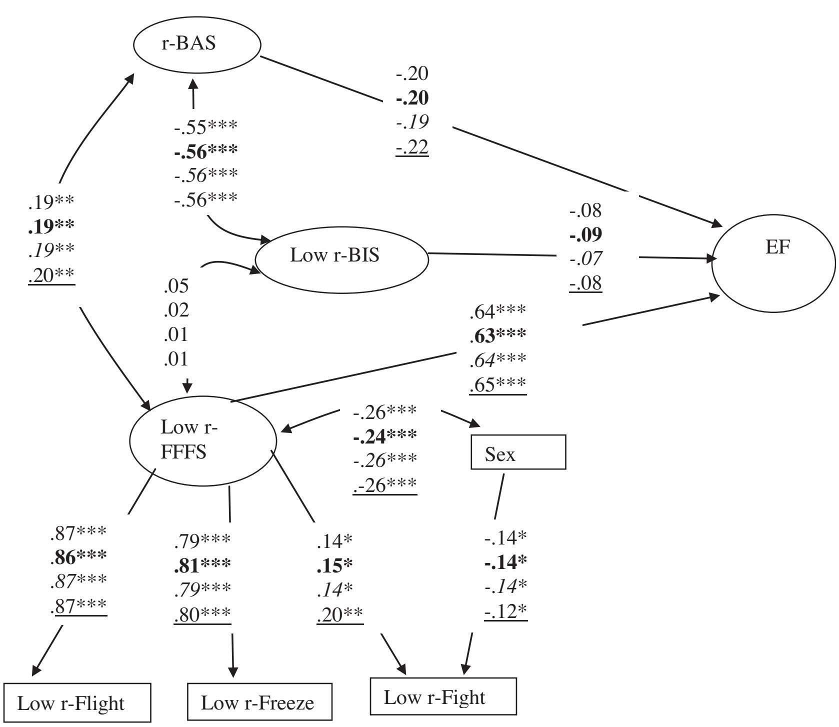

Fig. 1. Confirmatory factor analysis of the Jackson-5 (J5) model of r-RST in the prediction of executive functioning.

Table 3
Latent variable modeling of r-RST in the prediction of a latent variable of executive functioning.

	R^2	Chi Sq	df	p	GFI	AGFI	CFI	RMSEA	AIC	BIC
r-RST CFA1	.39	327.67	155	<.001	.91	.88	.90	.06	437.67	445.02
r-RST CFA2	.38	275.31	154	<.001	.93	.90	.93	.05	387.31	394.80
r-RST CFA3	.38	256.02	137	<.001	.93	.90	.92	.05	362.02	368.75
r-RST CFA4	.39	233.27	136	<.001	.93	.91	.94	.05	341.27	348.13

r-RST CFA1 = Initial model with 6 items predicting r-BAS and r-BIS (model from Jackson, 2009).
r-RST CFA2 = As 1 but with Item 27 used as observed variable of r-BIS and r-FFFS.
r-RST CFA3 = As 1 but with Item 27 deleted.
r-RST CFA4 = As 1 but with Item 27 deleted and link between r-Fight and r-BAS (estimate = .28***).

resource allocation theory (e.g., Kanfer & Ackerman, 1989; Norman & Bobrow, 1975), which argues attentional resources comprise a limited set of cognitive processes that can be directed towards various activities. As resources are directed toward an activity, there should be fewer remaining to be directed elsewhere. From this perspective, flight concerns the reallocation of cognitive resources from the frontal cortex (associated with higher cognitive processes of planning etc.) to emotional (i.e. fear) and motor centers of the brain (preparation for action). From an evolutionary perspective, readiness to flee a dangerous event as quickly as possible is an automatic reaction likely to contribute to survival. Consequently, a threat leads to quicker preparation for action but poorer executive functioning. We see this mechanism as supporting the dual process model.

In minor support of Hypothesis 3, we found some correlational evidence o-BAS was predictive of the Stroop. This may be due to greater neural efficiency (Gray et al., 2005). We could not find support for Hypothesis 1 because o-BIS and r-BIS were unrelated to executive functioning. This may be because anxiety may be operationalized in multiple ways – for example as disinhibition or passive avoidance (e.g., Jackson, 2008b).

We think evidence in favor of r-Flight, or more generally the r-FFFS, correctly identifies the importance of fear to personality. This is an important finding given that fear is rarely measured or confounded with anxiety (such as in o-BIS and neuroticism in the FFM). Another recent study using the J5 scales also found FFFS but not r-BIS to be associated with low work engagement via a cognitive factor of psychological (in)flexibility for those workers with highly demanding jobs (Clark & Loxton, 2012). This also supports the importance of understanding the separate roles of r-FFFS from r-BIS.

The results of our confirmatory factor analyses of the J5 model of r-RST (Jackson, 2009) are useful to present. Results support the proposed model and the perspective how fear has a negative influence on executive functions. Moreover, results support the requirement for sex to be partialled when relating r-Fight to r-FFFS as proposed by Jackson (2009) and suggest a further path from r-Fight to r-BAS may be useful (as foreshadowed by Smillie et al., 2006 and Jackson, 2009). Figure 1 shows r-FFFS can be independent from r-BIS, and that r-BIS can have a positive relationship with r-BAS. Both are expected results from r-RST. Perhaps more debatable is our use of a latent variable to summarize executive functioning since they are a diverse collection of executive processes.

Overall, this research finds an important link between executive functions which are understood to be "effortful" or "controlled," and neurocognitive personality processes associated with temperament understood to be "routine" or "automatic". This evidence provides support for a view in which there are inter-relationships between these dual systems (such as argued by Elliot & Thrash, 2002, 2010; Jackson, 2008a, 2011). We think that unraveling the relationships is key to understanding mechanisms likely to underlie personality structure and which will prove more informative than personality structures derived from exploratory factor analysis.

Modest relations between objective measures of executive functions and self-report measures of RST were expected. Nevertheless, the low size of the correlations between RST variables and executive functioning, as well as recognition that R^2 is never greater than 0.40, suggests other important influences yet to be identified. Other limitations of our work are that whilst the differences between these systems are well-accepted in the literature the reality of there being a clear distinction seems unlikely and the causality implied has yet to be tested.

In summary, we find that r-Flight predicts executive functioning, which we think is best explained by cognitive resource theory and relationships between automatic and effortful systems. We believe that theory-based mechanistic models of personality based on dual systems provide firm foundations for the better understanding of personality than models based on exploratory factor analysis.

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