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Neuroticism, intelligence, and intra-individual variability in elementary cognitive tasks: Testing the mental noise hypothesis

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Some studies show positive correlations between intraindividual variability in elementary speed measures (reflecting processing efficiency) and individual differences in neuroticism (reflecting instability in behaviour). The so-called neural noise hypothesis assumes that higher levels of noise are related both to smaller indices of processing efficiency and greater levels of neuroticism. Here, we test this hypothesis measuring mental speed by means of three elementary cognitive tasks tapping similar basic processes but varying systematically their content (verbal, numerical, and spatial). Neuroticism and intelligence are also measured. The sample comprised 196 undergraduate psychology students. The results show that (1) processing efficiency is generally unrelated to individual differences in neuroticism, (2) processing speed and efficiency correlate with intelligence, and (3) only the efficiency index is genuinely related to intelligence when the colinearity between speed and efficiency is controlled.

Neuroticismo, inteligencia y variabilidad intra-individual en tareas cognitivas elementales: contraste de la hipótesis del ruido neuronal. Una serie de estudios han observado correlaciones entre la variabilidad intra-individual en medidas de velocidad mental en tareas cognitivas elementales (que expresa la eficiencia de procesamiento) y las diferencias individuales en neuroticismo (que expresa la inestabilidad de la conducta). La conocida como hipótesis del ruido neuronal asume que mayores niveles de ruido se relacionan tanto con menores índices de eficiencia de procesamiento como con mayores niveles de neuroticismo. En este artículo se contrasta esta hipótesis midiendo la velocidad mental mediante tres tareas cognitivas elementales que valoran procesos básicos similares pero que varían sistemáticamente su contenido (verbal, numérico y espacial). También se mide el neuroticismo y la inteligencia. La muestra estuvo compuesta por 196 estudiantes de psicología. Los resultados indican que (1) la eficiencia de procesamiento no se relaciona con las diferencias individuales en neuroticismo, (2) tanto la velocidad como la eficiencia de procesamiento correlacionan con la inteligencia y (3) solamente el índice de eficiencia se relaciona genuinamente con la inteligencia cuando se controla la co-linealidad entre velocidad y eficiencia.

By means of elementary cognitive tasks is it possible to measure (a) number of mistaken responses (accuracy), (b) mean reaction time (RT), and (c) the standard deviation of RT (RTSD) over *n* trials (Deary, 2000; Jensen, 1998, 2007). Accuracy is usually very high in these tasks, RT reflects processing speed, and RTSD measures the intraindividual variability in RT. *Speed* and *efficiency* of information processing in these elementary cognitive tasks must be distinguished. Speed is measured by RT, whereas RTSD captures processing efficiency.

The processing efficiency component of speed tasks has been linked to the periodicity in the excitatory potential of neurons. The speed of transmission from neuron to neuron depends on both the speed of axonal and synaptic conduction and the probability that impulses are delayed by oscillation of the neurons' excitatory potentials. The phase of excitatory potential –oscillating below and above the threshold of excitation by a given stimulus—is random with respect to the onset of the stimulus, and, therefore, the probability that the stimulus will be propagated varies depending on whether the potential is above or below the excitability threshold. This is the rule: the faster the oscillation, the shorter is the average difference in time between the quickest and slowest reactions to the stimulus (Anderson, 1994; Jensen, 1998; Vernon et al., 2000). Jensen (1998) argues that periodic oscillation of the action potentials of assemblies of neurons could underlie the variability in speed tasks.

This neural oscillation model is thought to represent *neural noise* (Barrrett et al., 1990; Callaway, 1979; Fairbank et al., 1991; Jensen, 1992). By analogy, «the static and cross talk on a bad telephone line, reduces the efficiency of communication and thereby increases the time of the callers' conversation, because many words and phrases have to be repeated to get the message across» (Jensen, 1998, p. 255).

What's neural noise?

More than forty years ago, FitzHugh (1961) noted that neurons can be described as oscillators in which the voltage across the cell

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membrane changes according to two processes: (a) the fast action potential (or spike) and (b) the slower-varying post-synaptic potential.

More recently, Ward (2003) has suggested that neural oscillations are closely related to basic cognitive processes. «*Fundamental cognitive processes arise from the synchronous activity of neurons in the brain (…) Specific oscillations can be identified with particular cognitive processes: theta and gamma rhythms with memory encoding and retrieval, alpha and gamma rhythms with attentional suppression and focusing, and global synchronization at the gamma frequency with consciousness*» (p. 558).

There are some models linking neural oscillations to memory processes (Almeida and Idiart, 2002; Clayton and Frey, 1997; Lisman and Idiart, 1995). For instance, Lisman and Idiart's (1995) model postulates a connection between theta and gamma oscillations produced from the neural basis of memory span tasks (short-term memory and working memory; see Colom et al., 2006). Memories are stored in groups of pyramidal neurons firing in synchrony. This firing dissipates with time, so this requires some sort of refreshing. The individual memories are refreshed at the gamma frequency, whereas the overall refresh cycle is repeated at the theta frequency.

As argued by Ward (2003) if memories are refreshed at the gamma rate once per theta cycle, then the number of items that can be held in short-term memory corresponds to the gamma frequency divided by the theta frequency, or about 40/6 = 7 memories without experiencing a significant loss (Miller, 1956). Importantly, this model may account for variations in short-term memory capacity with task factors and individual differences: «*as theta can vary at least over the range 3.5 Hz to 7 Hz and gamma over the range 30 Hz to 70 Hz, a fairly broad range of capacities can be accommodated by the model, from around 3 or 4 items to nearly 20 items*» (Ward, 2003, p. 556).

Flehmig et al. (2007) have reported that higher values for RTSD are systematically detected for patients with focal frontal lobe lesions, traumatic brain injury, epilepsy, dementia, mild cognitive impairment, schizophrenia, attention deficit/hyperactivity disorder, and anxiety-related personality traits. This suggests that processing efficiency can have broad effects on several cognitive and non-cognitive factors. However, whereas we found significant associations between processing efficiency and cognitive abilities, we failed to find a relationship between neuroticism and the index of intraindividual variability.

Neural noise, cognitive ability, and neuroticism

It is known that IQ correlates with variability in RT: people scoring higher in IQ tests show less variability. Even in university students, a significant negative correlation is found between RTSD and IQ, and this correlation tends to be larger than the correlation between IQ and RT. Further, RTSD is correlated to IQ independently of RT (Larson & Alderton, 1990; Kranzler, 1992).

With respect to personality measures, Eysenck & Eysenck's (1985) summary has shown that neuroticism (N) correlates with instability in behaviour. They have related individual differences in N to the excitability level of the limbic system (see Matthews & Gilliland, 1999 for an update of this view). This *excitability* might be related to cognitive processes. If these processes are measured by speed tasks, it is reasonable to predict a positive correlation between N and the variability of reaction time (RTSD).

Robinson and Tamir (2005) have hypothesized that «*N would be associated with variability in stimulus-response behaviour as measured by reaction time*» (p. 108). As noted above, RTSD can be considered a proxy quantitative index of mental noise. Baumeister (1998) reported a significant association between intelligence and the variability of response times in laboratory tasks. Deary and Caryl (1997) stated that greater standard deviations reflect less efficient neural transmission. Rabbitt et al. (2001) found that RTSD is stable across tasks and over time, which suggests that this measure should be considered seriously. Therefore, RTSD can be thought as a reliable estimate of the level of noise during transmission within a given information processing system. The variability of RT can be considered as indexing the *efficiency* of basic cognitive processes.

Robinson & Tamir (2005) showed that N correlates with the RTSD derived from speed task measuring several basic, but diverse, cognitive operations. Across three studies involving (1) multiple semantic distinctions, (2) the Stroop task, and (3) simple, go/no-go, and choice tasks, they did find correlations ranging from .22 (first study) to .41 (second study). Therefore, they confirmed a positive association between N and RTSD.

However, Robinson and Tamir (2005) used quite heterogeneous elementary cognitive tasks –which might lead to confusing theoretical interpretations– and did not measure intelligence. It is important to replicate these sorts of findings, because the neural noise hypothesis is seen as a promising avenue to disentangle the puzzle of the relationships between cognitive and non-cognitive areas in Psychology (Matthews & Gilliland, 1999). Therefore, here we administer three speed tasks requiring the same basic cognitive processes, but with different content domains –verbal, numerical, and spatial. Further, several diverse intelligence measures are also administered to get a more comprehensive picture than that presented by studies such as the reported by Robinson and Tamir (2005).

Method

Participants

196 university psychology undergraduates took part in the study (83% were females). They participated to fulfil a course requirement. Their mean age was 19.9 (SD= 3.3).

Instruments

Mental speed was measured by three tasks tapping the same basic cognitive processes, but varying their content domain –verbal, numerical, and spatial. The three speed tasks were based on the sequential presentation of a very small sized memory set composed by one or two simple stimuli, a fixation point, and the target to which the participant is requested to respond as quickly and accurately as possible.

In the verbal speed task, one or two letters are sequentially displayed for 650 ms. each. Those letters define a memory set that can comprise uppercase and lowercase letters. After the last displayed letter, a fixation point appears for 500 ms. Finally, the probe letter appears in order to decide, as quickly and accurately as possible, if it has the same *meaning* as one of the letters presented within the memory set. Therefore, the letters' physical appearance (uppercase or lowercase) must be ignored. Half of the trials request a positive answer. The experimental trials range from one to two letters (2 levels × 30 trials each= 60 trials total). The

obtained scores are: mean accuracy, as well as mean RT, and mean RTSD for the correct answers only.

In the quantitative speed task, one or two single digits are sequentially displayed for 650 ms. each. Those digits define a memory set. After the last displayed digit, a fixation point appears for 500 ms. Finally, the probe digit appears in order to decide, as quickly and accurately as possible, if it can be divided by one of the digits presented within the memory set. Half of the trials request a positive answer. The experimental trials range from one to two digits (2 levels × 30 trials each= 60 trials total). The obtained scores are: mean accuracy, as well as mean RT, and mean RTSD for the correct answers only.

In the spatial speed task, one or two arrows are sequentially displayed for 650 ms. each. Those arrows define a memory set. The arrows can be displayed in one of seven orientations (multiples of 45 degrees). After the last displayed arrow, a fixation point appears for 500 ms. Finally, the probe arrow appears in order to decide, as quickly and accurately as possible, if it has the same orientation of one of the arrows presented within the memory set. The arrows have distinguishable shapes in order to guarantee that their orientation is both memorized and evaluated. Half of the trials request a positive answer. The experimental trials range from one to two arrows (2 levels × 30 trials each= 60 trials total). The obtained scores are: mean accuracy, as well as mean RT, and mean RTSD for the correct answers only.

The Spanish standardization of the Revised NEO Personality Inventory (NEO-PI-R) comprises 240 items measuring extraversion (E), agreeableness (A), conscientiousness (C), neuroticism (N), and openness to experience (O). The inventory also measures six subordinate facets for each of the above five personality factors. Here we use the Spanish standardization of the NEO-FFI, the abbreviated version of the NEO-PI-R comprised by its first 60 items. The items are answered on a five point scale, ranging from «strongly disagree» to «strongly agree». Only the N scale is considered in the present study.

Finally, intelligence was measured by nine standardized tests tapping the constructs of abstract-fluid intelligence (Gf), verbal-crystallized intelligence (Gc), and spatial intelligence (Gv). Gf was measured by the Advanced Progressive Matrices Test (APM, screening version, even numbered items), the abstract reasoning subtest from the Differential Aptitude Test Battery-5 (DAT-AR-5, screening version, even numbered items) (Bennett et al., 1990), and the inductive reasoning subtest from the Primary Mental Abilities Battery (PMA-R) (Thurstone, 1938). Gc was measured by the verbal reasoning subtest from DAT (DAT-VR-5, screening version, even numbered items), the numerical reasoning subtest from the DAT (DAT-NR-5, screening version, even numbered items), and the vocabulary subtest from the PMA. Gv was measured by the rotation of solid figures test (Yela, 1969), the mental rotation subtest from the PMA (PMA-S), and the spatial relations subtest from the DAT-5 (DAT-SR-5, screening version, even numbered items).

Procedure

Testing took place in three sessions. The first and second sessions were dedicated to intelligence and personality testing, whereas the third session was dedicated to the computerized speed tasks –the verbal speed task was administered first, then the spatial tasks, and finally the numerical task. The tests and tasks were administered in groups of no more than 20 participants for a total of 3 hours/sessions approximately.

Data analysis

Before computing correlations among the main measures of interest, we transformed the speed measures following Robinson and Tamir's (2005) procedure. Raw millisecond values (at the mean and standard deviation levels) were log transformed to normalize the distributions. Further, log latencies at the mean level 2.5 standard deviations below and above the grand latency mean, were replaced with the grand mean. Finally, we calculated a residual standard deviation variable through a regression analysis predicting RTSD on the basis of RT. This computational procedure was followed for the three speed tasks. It is important to note that this is done to compute the correlation between RTSD and the remaining measures controlling for the effect of RT over RTSD. The procedure gives similar results to those from semi-partial correlations.

Results

Table 1 shows the descriptive statistics for all the considered measures. The reliability indices (Cronbach's α) for the speed tasks were: .90 (verbal and spatial speed), and .93 (numerical speed). Cronbach's α for N was .87. With respect to the intelligence measures, Cronbach's α values were: APM= .66, PMA-R= .87, DAT-AR= .88, PMA-V= .79, DAT-VR= .68, DAT-NR= .82, Rotation of solid figures= .74, PMA-S= .73, DAT-SR= .84.

Table 2 shows the Pearson correlations between N and the speed measures transformed as described on the data analysis section.

Table 1
Descriptive statistics for the speed, personality (N) and intelligence measures

Measures	Mean	SD
MENTAL SPEED		
Verbal Speed (accuracy)	56.59	2.85
Verbal Speed (RT)	640.29	153.84
Verbal Speed (RTSD)	248.67	203.71
Numerical Speed (accuracy)	53.20	4.94
Numerical Speed (RT)	975.69	300.99
Numerical Speed (RTSD)	476.83	268.49
Spatial Speed (accuracy)	56.47	2.91
Spatial Speed (RT)	661.98	158.37
Spatial Speed (RTSD)	215.98	122.41
PERSONALITY		
Neuroticism (N)	23.46	7.40
INTELLIGENCE		
APM	10.93	2.67
PMA-R	18.57	4.98
DAT-AR	12.70	3.90
PMA-V	30.99	6.59
DAT-VR	12.85	3.10
DAT-NR	10.65	3.44
Solid Figures	7.45	3.78
PMA-S	25.25	10.67
DAT-SR	14.28	4.79

Table 2 shows that intraindividual variability, quantified by RTSD (log), does not correlate with individual differences in neuroticism (N).

Of interest are the large correlations between RT (log) and RTSD (log) for the three speed tasks. Participants showing large RTs (less *speed*) also suffer from greater intraindividual variability (less *efficiency*). This is consistent with the neural noise hypothesis (Jensen, 1998, 2007) and reinforces the conclusion that N is not related to this solid estimate of neural noise. Further, the correlations among RTSD indices across the speed tasks were: .34 (verbal-numerical), .51 (verbal-spatial), and .46 (spatial-numerical). This agrees with the results found by Rabbitt et al. (2001) showing stability across speed tasks for the index of processing efficiency.

Table 2
Correlations between Neuroticism and Speed Measures

	Neuro-ticism	Accu-racy	RT (log)	RTSD (log)	St. Res.
VERBAL SPEED					
Accuracy	-.05	–			
RT (log)	.02	.01	–		
RTSD (log)	.04	-.09	.80*	–	
Standardized Residual	.04	-.17	.00	.61*	–
NUMERICAL SPEED					
Accuracy	-.18	–			
RT (log)	.05	-.01	–		
RTSD (log)	.15	-.13	.89*	–	
Standardized Residual	.24*	-.26*	.00	.45*	–
SPATIAL SPEED					
Accuracy	-.01	–			
RT (log)	-.03	.09	–		
RTSD (log)	-.02	-.03	.75*	–	
Standardized Residual	.00	-.16	.00	.66*	–

* $p<.01$

Table 3
Correlations among intelligence, speed and neuroticism

	General Intelligence	Gf	Gc	Gv
VERBAL SPEED				
Accuracy	.14	.09	.09	.15
RT (log)	-.33*	-.26*	-.29*	-.28*
RTSD (log)	-.38*	-.33*	-.30*	-.32*
Standardized Residual	-.22*	-.22*	-.15	-.17
NUMERICAL SPEED				
Accuracy	.32*	.34*	.30*	.18
RT (log)	-.44*	-.31*	-.47*	-.32*
RTSD (log)	-.45*	-.34*	-.47*	-.32*
Standardized Residual	-.15	-.16	-.15	-.08
SPATIAL SPEED				
Accuracy	.24*	.21	.17	.22*
RT (log)	-.34*	-.28*	-.28*	-.30*
RTSD (log)	-.42*	-.38*	-.31*	-.35*
Standardized Residual	-.25*	-.27*	-.16	-.20*
NEUROTICISM	-.08	-.09	-.12	.00

* $p<.01$

We are still required to test the role of intelligence in this picture. To accomplish that, we compute the correlation between intelligence, speed, and neuroticism. Note that one general intelligence estimate, as well as separate composite measures for Gf, Gc, and Gv were computed (Table 3).

The results indicate that the correlation between N and the intelligence estimates are not statistically significant. Further, all the intelligence estimates correlate with both RT (log) and RTSD (log), irrespective of the speed tasks' content domain (values range from -.26 and -.47, $p<.01$).

In order to cross-validate the finding of significant correlations between the speed standardized residuals (RTSD unpredicted by RT) and the intelligence measures (Table 3), we computed the partial correlation between general intelligence and the speed measures (RT log) controlling for the efficiency measures (RTSD log) across the speed tasks, as well as the correlation between intelligence and the measures of efficiency (RTSD log) controlling for the speed measures (RT log) across tasks. Interestingly, RT log no longer shows significant correlations with intelligence for none of the speed measures (verbal= -.05; numerical= -.09; spatial= -.05), whereas RTSD log still shows significant correlations with intelligence across the speed measures (verbal= -.21; numerical= -.14, *ns*; spatial= -.25). This is also the case for Gf, Gc, and Gv.

Finally, it might be interesting to note that the standardized residual score for the numerical speed task shows (1) a significant correlation with N (r= .24, $p<.01$, Table 2), and (2) non significant correlations with general intelligence, Gf, Gc, and Gv (Table 3).

Discussion

Here we have tested the neural noise hypothesis regarding neuroticism (N). Based on the theoretically relevant distinction between *speed* and *efficiency* of information processing, we measured these key parameters after three speed tasks very close in their processing requirements but varying in their content. Speed was measured by reaction time (RT), whereas reaction time standard deviation (RTSD) was thought to tap processing efficiency. It was hypothesized that more intraindividual variability on the speed measures should be positively correlated with N if both measures are linked by means of a presumably common underlying neural base (Robinson and Tamir, 2005). The results have several points of interest.

First, we failed to find a positive association between the processing proxy estimate of neural noise (RTSD) and individual differences in neuroticism (N) across the modelled tasks of mental speed. Robinson and Tamir's (2005) 3rd study is considered by them the final step in the way [«*Study 3 contributes a number of important findings to the article as a whole*» (p. 112)]. Across their three simple reaction time tasks, they found that the correlation between N and RTSD must be necessarily related to «general» information processing. However, if this is the case, why we have failed to find comparable results with our reaction time tasks?

We may think in three tentative explanations: (a) they have tested a very small sized sample (N= 43) and perhaps with extreme scores on N (although we cannot test this latter possibility, because, surprisingly, they did not report mean and SD values for N), (b) their tasks comprise a very large number of homogeneous trials (> 300) which can produce great degrees of fatigue in participants scoring high in N, and (c) the higher the complexity of the elementary speed task, the lower the correlation between N and processing efficiency, because of the probable role of individual differences in intelligence. Nevertheless, we acknowledge that any straight explanation is currently unavailable.

Second, speed (RT log) and efficiency (RTSD log) measures show a high correlation across speed tasks. This finding supports the view that participants showing higher speed of processing (smaller RTs) are also more efficient (less RTSDs). Further, RTSD stability across speed tasks was observed, which reinforces the statement that RTSD can be considered a reliable estimate of the level of noise during transmission within the human information processing system (Rabbitt et al. 2001).

Third, intelligence, broadly represented in the present study by several diverse tests, is not related to N. This is consistent with the presumption held by Robinson and Tamir (2005): «*the relations showed here cannot be due to intelligence, as neuroticism and intelligence are almost completely, if not completely unrelated*» (p. 112). Here we have shown that they were correct in their statement.

Fourth, intelligence was significantly related to all the speed measures across content domains: the higher the speed and efficiency of information processing, the greater the intelligence level, irrespective of the fluid, crystallized, or spatial nature of the intelligence measure.

Finally, a very interesting finding emerges from the reported results: processing efficiency, but not speed per se, is genuinely related to intelligence. Controlling for their collinearity resulted in significant correlations between processing efficiency (RTSD log) and intelligence. However, the correlation between processing speed (RT log) and intelligence was no longer statistically significant (Kranzler, 1992; Larson & Alderton, 1990).

This latter finding suggests that intraindividual variability in response times, as reflecting more neural noise, is related to individual differences in intelligence (except for the numerical speed task, for unknown reasons –although its greater complexity, as reflected by larger RTs and lower accuracy levels, can help to find a reasonable explanation). However, mere speedier responses are not genuinely related to these differences in intelligence.

As noted by one anonymous reviewer, data shown on Table 3 indicates that pure processing efficiency estimates for the administered speed tasks correlate mainly with abstract-fluid intelligence (Gf), whereas its correlation with verbal-crystallized (Gc) and visuo-spatial intelligence (Gv) is generally weak and non-significant. This finding is consistent with Martínez and Colom (in press) who showed that working memory capacity and processing efficiency predict fluid, but not crystallized and spatial intelligence. Their results were thought to support the hypothesis that if Gf is biologically rooted, whereas Gc and Gv are more prone to non-biological factors such as learning, cultural investment, and so forth, then processing efficiency would be related to Gf mainly.

In summary, the present study was unable to replicate significant associations between individual differences in N and a proxy estimate of neural noise, namely, the intraindividual variability of response times derived from elementary cognitive tasks. The role of intelligence was also assessed, finding that this psychological construct is not related to neuroticism. Finally, processing efficiency, but not processing speed per se, was found to be genuinely related to intelligence. We underscore that the neural noise hypothesis, as described at the introduction section, fits the biological base of cognitive functions such as memory span (Colom et al., 2007 b). Individual differences in theta and gamma activity could underlie the proposed cognitive indices of intraindividual variability, such as the reaction time standard deviation (RTSD) obtained from elementary cognitive tasks. Here we have shown that this index of processing efficiency, derived from three speed tasks modelled after the Sternberg memory scanning paradigm, correlates with scores in fluid, crystallized, and spatial intelligence (Colom et al., 2007 a). Therefore, participants with higher levels of intelligence show cognitive patterns reflecting less neural oscillations and lower levels of neural noise, which in turn leads to more processing efficiency.

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