Original Article

Neuroticism and Speed-Accuracy Tradeoff in Self-Paced Speeded Mental Addition and Comparison

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Abstract. Previous research suggests a relationship between neuroticism (N) and the speed-accuracy tradeoff in speeded performance: High-N individuals were observed performing less efficiently than low-N individuals and compensatorily overemphasizing response speed at the expense of accuracy. This study examined N-related performance differences in the serial mental addition and comparison task (SMACT) in 99 individuals, comparing several performance measures (i.e., response speed, accuracy, and variability), retest reliability, and practice effects. N was negatively correlated with mean reaction time but positively correlated with error percentage, indicating that high-N individuals tended to be faster but less accurate in their performance than low-N individuals. The strengthening of the relationship after practice demonstrated the reliability of the findings. There was, however, no relationship between N and distractibility (assessed via measures of reaction time variability). Our main findings are in line with the processing efficiency theory, extending the relationship between N and working style to sustained self-paced speeded mental addition.

Keywords: concentration, trait anxiety, sustained attention, reaction time variability, performance efficiency

The personality dimension "neuroticism" (N) was originally introduced by H.J. Eysenck (1947), for whom it was a dimension ranging from emotional lability to stability. Others, such as Cattell (1965), conceptualized N as trait anxiety within the normal population. In fact, individuals with high scores on N are often characterized as anxious with a generalized tendency to experience negative emotions (e.g., Eid & Diener, 1999), and are often found to be less effective than low-N individuals in regulating cognitive functioning (Bolger & Schilling, 1991). It is also well established that high levels of N and related traits (e.g., trait anxiety, test anxiety) are generally associated with reduced performance levels, particularly on tasks that strain working memory capacity (Eysenck, Derakshan, Santos, & Calvo, 2007). The detrimental effects are primarily associated with states of worry and emotional disturbance, considered to be more frequently experienced by anxious and highly neurotic individuals. Nevertheless, the empirical findings on the N-performance relationship provide a rather inconsistent picture: Whereas several studies found evidence for both positive (e.g., Eysenck et al., 2007; Smillie, Yeo, Furnham, & Jackson, 2006) and negative (e.g., Newton, Slade, Butler, & Murphy, 1992; Stelmack, Houlihan, & McGarryroberts, 1993) relationships between N and reaction-time performance, often weak or even absent correlations were reported (e.g., Colom & Quiroga, 2009; Corr, 2003; Stahl & Rammsayer, 2007; Strobel et al., 2007). This suggests that there is no straightforward relationship between N and cognitive task performance.

Despite the divergence of empirical findings, there is agreement that the relationship between N and performance is moderated by task complexity, as high-N individuals often show performance decrements only in complex tasks but not in easy ones (e.g., Eysenck et al., 2007; Humphreys & Revelle, 1984). One of the most influential theories aiming to explain this relationship was formulated by M.W. Eysenck and colleagues. According to PET, restrictions in available working memory capacity are responsible for reduced performance levels in highly anxious/neurotic individuals, because these individuals are more likely to have task-irrelevant worrisome thoughts that occupy working memory. The model assumes that worry has two major effects (Eysenck et al., 2007, p. 337): First, it results in cognitive interference by preempting processing capacity. It is assumed that, when worrisome thoughts reach consciousness, they consume parts of the limited resources, which are then less available for current task processing. This competition results in a decline in cognitive efficiency (e.g., Sarason, Sara-

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son, & Pierce, 1990). Second, worrying involves increased effort to compensate for worry-induced performance impairments by allocating additional attentional resources to the current task. This includes an increased motivation to minimize negative emotional states and to inhibit upcoming intrusions from long-term memory (e.g., Humphreys & Revelle, 1984).

In easy tasks, such as forewarned simple and choice RT tasks with easy stimulus–response (S–R) mappings (e.g., Steinborn, Rolke, Bratzke, & Ulrich, 2008, 2009), the limited capacity may be sufficient to accomplish the task requirements. Thus, N-related individual differences may not easily be revealed in easy tasks (Robinson & Tamir, 2005; Robinson, Wilkowski, & Meier, 2006). In complex tasks, however, the limitation in processing capacity should have detrimental effects on cognitive efficiency. An important prediction of PET is that high-N individuals, since they are easily aroused when confronted with evaluative situations, try to compensate for their decreased efficiency by enhancing mental effort. This is mediated by an increased level of unspecific energization, which is assumed to result in a specific working style, characterized by sacrificing accuracy for speed. For example, Ashcraft and colleagues (Ashcraft & Faust, 1994; Ashcraft & Kirk, 2001) reported a relationship between test anxiety/trait anxiety and the speed–accuracy tradeoff during mental addition: Highly anxious individuals were not only less efficient in their performance but also showed a pronounced tendency to maintain response speed at the expense of accuracy, and this tendency increased with task difficulty. Similar results were reported by others (e.g., Szymura & Wodniecka, 2003).

Proceeding from PET as general theoretical framework, N-related performance differences should preferably be observable in tasks requiring working memory and the continuous allocation of attention. To this end, we employed the Serial Mental Addition and Comparison Task (SMACT), which has several advantages, for example, it does not discriminate against left-handed participants as do mental addition and verification tasks (Zbodroff & Logan, 1990). Also, item difficulty can be flexibly manipulated via increasing problem size (Ashcraft & Kirk, 2001), and item-set size (the number of items mapped onto a particular response) can be manipulated to prevent individuals from building up item-specific stimulus–response associations. We asked whether there are N-related individual differences in performance and whether there is an N-related speed–accuracy tradeoff. According to PET, individuals with high levels of N should exhibit lower performance efficiency and a pronounced tendency to sacrifice accuracy for speed. To this end, we analyzed average response speed, accuracy, and response speed variability. Apart from N, extraversion (E) and psychoticism (P) were assessed as major dimensions of H. J. Eysenck's personality theory, and the Behavioral Inhibition and Activation System (BIS/BAS) scales were used as control.

Method

Participants

A student-based sample of 99 volunteers (44 male, 55 female; mean age = 24.5 years, *SD* 5.1 years) participated in the study. Most of them were right-handed (9 left-handed), and all of them had normal or corrected-to-normal vision. All of them reported to be in good health condition. The sample was recruited via advertisements on the university campus of the Dresden University of Technology. Participants obtained course credit points or money for participation and received feedback after the testing sessions.

Eysenck Personality Questionnaire-Revised

The German short version of the EPQ-Revised (EPQ-RK) was used (Ruch, 1999). The EPQ-RK is a 50-item self-report inventory and assesses three major dimensions of personality: extraversion (E), neuroticism (N), and psychoticism (P).

Behavioral Inhibition System/Behavioral Activation System Scales (BIS/BAS)

The German version of the BIS/BAS scales was used (Strobel, Beauducel, Debener, & Brocke, 2001). The BIS/BAS scales are a 24-item self-report inventory that assesses individual differences in punishment and reward sensitivity. The scales are based on the biobehavioral personality theory of Gray (1982) and were originally developed by Carver and White (1994). The BIS scale includes items that refer to responses to the anticipation of punishment, whereas the BAS scale includes items that refer to responses to the anticipation of reward. There are three BAS subscales: The BAS Drive (D) scale includes items pertaining to the persistent pursuit of desired goals; the BAS Fun Seeking (FS) scale includes items referring to both a desire for new rewarding events and a willingness to approach a potentially rewarding event on the spur of the moment; the BAS Reward Responsiveness (RR) scale includes items that focus on positive responses to the occurrence or anticipation of reward.

Description of the SMACT

The serial mental addition and comparison task (Restle, 1970; Steinborn, Flehmig, Westhoff, & Langner, 2008) was employed as performance measure. It was administered twice within a test-retest interval of three days. This task requires participants to self-pace their responses, since each item in a trial is presented until response and replaced immediately after the response by the next item. As in other

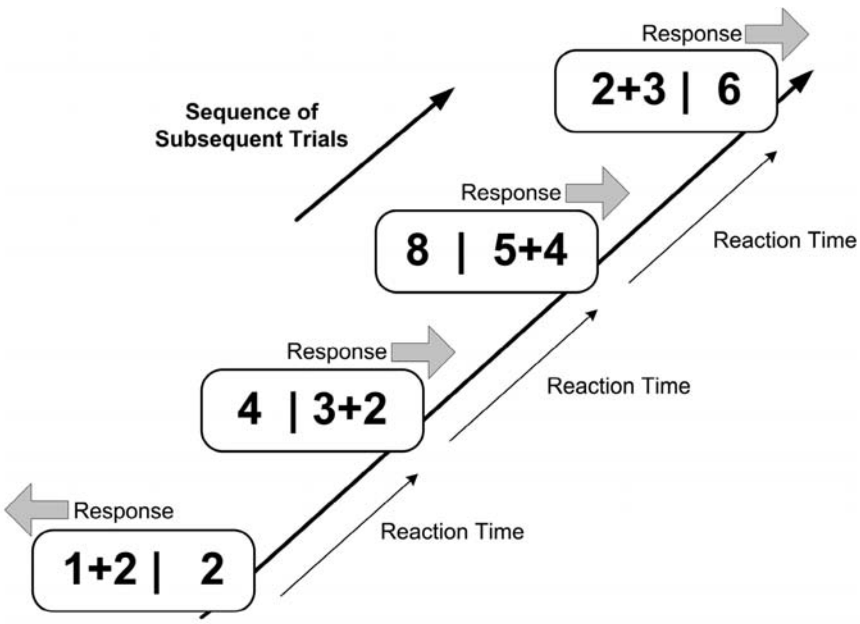

Figure 1. Example of a typical sequence of trials in the serial mental addition and comparison task (SMACT). Participants have to indicate the side that shows the larger numerical value by pressing either a left or right response key. A stimulus is presented immediately after having responded to the previous one.

self-paced speed tests, no feedback is given, neither for erroneous responses nor for too slow responses. In each trial, an addition term together with a single number is presented; both are spatially separated by a vertical bar (e.g., "4 + 5 | 10"). Participants are required to solve the addition task and compare the result with the numerical value of the single number. This value was either one point smaller or one point larger than the result of the addition but never of equal value. Participants were required to indicate the larger numerical value by pressing either the left or right shift key as fast as possible, in accordance with the side the larger value was presented at. When the value on the left side was larger (e.g., "2 + 3 | 4"), they had to respond with the left key, and when the number value on the right side was larger (e.g., "5 | 2 + 4"), they had to respond with the right key (Figure 1).

Procedure

A large set of 148 items (problem size ranging from 4 to 19) was used to prevent participants from building item-specific stimulus-response associations. Each item was presented only four times during a session, amounting to a total of 592 randomly presented trials. Altogether, the task lasted about 30 min. The experiment took place in a noise-shielded room and was run on a standard IBM-compatible personal computer with color display (19-inch, 150 Hz frequency), using the software Behringer Experimental Runtime System (ERTS; BeriSoft GmbH) for task presentation and response recording. Participants were seated at a distance of about 60 cm in front of the computer screen, and the stimuli were presented at the center of the screen. The questionnaires were administered after the experimental session of the first day.

Results

Correct responses longer than 100 ms and shorter than two standard deviations above the individual mean were used to compute RTM as a measure of response speed. In addition, we computed the median of response times RTMD, since this measure is much less affected by the proportion of very slow responses. The percentage of erroneous responses (EP) was computed as an index of accuracy. RTSD and RTCV were calculated as measures of absolute and relative (i.e., mean-corrected) response speed variability. RTSD is the intraindividual standard deviation of response times, and RTCV is RTSD divided by RTM and multiplied by 100 (Flehmig, Steinborn, Langner, Scholz, & Westhoff, 2007). Since erroneous responses were rare, we performed an arcsine transformation on EP before further analyses. Sample mean scores and standard deviations for performance measures and personality traits are given in Table 1. Descriptive analyses revealed that N showed a unimodal and symmetric distribution in the sample. N was uncorrelated with both extraversion and psychoticism and also with the overall BAS score and the BAS subscores. As expected, N was positively correlated with the BIS score (r = .30, $p < .01$).

The results of the correlational analysis are displayed in Table 2. A small but significant negative correlation between N and RTM was found, indicating that high-N individuals were faster in their average response speed than low-N individuals. This relationship remained not only stable but increased after practice (test: $r = -.17$, $p < .05$; retest: $r = -.26$, $p < .01$). There was also a positive correlation between N and EP, indicating that high-N individuals committed more errors than low-N individuals. This relationship was more pronounced in the second testing session, too (test: $r = .17$, $p <$

Table 1. Descriptive statistics for self-report data (EPQ, BIS/BAS) and performance in the serial mental addition and comparison task (SMACT)

	Scales	Session 1 (first test)				Session 2 (retest)			
		M	*SD*	Skewness	Kurtosis	*M*	*SD*	Skewness	Kurtosis
1	EPQ-N	5.03	3.04	0.31	–0.71	–	–	–	–
2	EPQ-E	7.43	3.17	–0.31	–0.75	–	–	–	–
3	EPQ-P	3.39	1.99	0.37	–0.68	–	–	–	–
4	BIS-overall	2.74	0.31	–0.30	–0.32	–	–	–	–
5	BAS-overall	3.07	0.31	0.24	–0.34	–	–	–	–
6	BAS-D	3.02	0.48	–0.10	–0.65	–	–	–	–
7	BAS-FS	2.90	0.48	0.39	–0.41	–	–	–	–
8	BAS-RR	3.25	0.36	0.10	–0.45	–	–	–	–
9	RTMD	1568	292	0.70	0.58	1339	256	0.73	0.34
10	RTM	1668	341	0.73	0.38	1413	291	0.62	0.04
11	EP	2.99	2.23	2.36	9.09	2.35	2.64	4.42	29.2
	EP (arcsine)	9.41	3.35	0.98	1.97	7.99	3.87	1.62	5.89
12	RTSD	899	445	1.67	3.57	686	342	1.34	2.48
13	RTCV	47	13	1.08	2.12	43	13	1.13	2.51

Notes. M = mean; *SD* = standard deviation of mean; Eysenck Personality Questionnaire (EPQ): N = neuroticism; E = extraversion; P = psychoticism; Behavioral-Inhibition/Behavioral-Activation System (BIS/BAS Questionnaire): BIS = Behavioral Inhibition System; BAS = Behavioral Activation System (overall score); D = BAS Drive subscore; FS = BAS Fun Seeking subscore; RR = BAS Reward Responsiveness subscore; Performance measures: RTMD = median reaction time (ms); RTM = mean reaction time (ms); EP = error rate (%) and arcsin-transformed error rate (%); RTSD = reaction time standard deviation (ms); RTCV = reaction time coefficient of variation.

Table 2. Intercorrelation of traits, correlations between personality and performance, and retest reliability of performance in the SMACT

		EPQ			BIS/BAS Scales					SMACT Session 1				
		N	E	P	BIS	BAS	D	FS	RR	RTMD	RTM	EP	RTSD	RTCV
		1	2	3	4	5	6	7	8	9	10	11	12	13
	1	–	.03	.10	**.30**	.05	.14	–.04	.02	**–.18**	**–.17**	**.17**	–.07	–.05
	2	–	–	**.26**	**–.19**	**.45**	**.31**	**.41**	**.26**	.07	.07	–.01	.07	.05
	3	–	–	–	**–.19**	**.19**	–.05	**.41**	.05	.01	.03	.01	.10	.11
	4	–	–	–	–	.05	.10	–.10	.12	.06	.05	–.08	.05	.04
	5	–	–	–	–	–	**.76**	**.64**	**.76**	.04	.04	.06	.05	.04
	6	–	–	–	–	–	–	.16	**.46**	.07	.08	.02	.09	.09
	7	–	–	–	–	–	–	–	**.19**	–.02	–.03	.02	.03	.05
	8	–	–	–	–	–	–	–	–	.04	.03	.09	–.01	–.06
SMACT Session 2 (Retest)	9	**–.27**	.04	.04	.02	.04	.07	.01	.02	**.96**	**.98**	**–.18**	**.74**	**.53**
	10	**–.26**	.04	.05	.02	.04	.06	.01	.01	**.99**	**.96**	–.16	**.85**	**.66**
	11	**.30**	.11	.05	–.12	.12	.10	.05	.10	**–.26**	**–.23**	**.78**	–.11	–.04
	12	–.16	.06	.07	.01	.04	.04	.07	–.04	**.72**	**.82**	–.07	**.89**	**.93**
	13	–.11	.04	.04	.03	.02	.03	.08	–.06	**.50**	**.62**	–.01	**.94**	**.84**

Notes. Test-retest reliability is shown in the main diagonal (denoted by gray); correlations for the first session are shown above, for the second session below the main diagonal. Significant correlations are denoted in **bold** ($N = 99$; $r \geq .17$, $p < .05$; $r \geq .24$, $p < .01$).

.05; retest: $r = .30$, $p < .01$). In contrast to previous observations (e.g., Robinson & Tamir, 2005), there was no significant relationship between N and RT variability. Also, there were no relationships between cognitive performance and other personality traits (see Table 2).

In a further step, we examined whether the observed correlations between N and performance speed and accuracy arise from a linear-monotonic relationship or from a rather nonlinear relationship. To this end, we performed a within-subject ANOVA to examine the effect of session (levels: test vs. retest) and N (levels: low-N vs. high-N) on the speed (RTM, RTMD) and accuracy (EP) of performance. The sample was divided into a low-, medium-, and high-N group such that each group comprised 33.3% of the sample (see Table 3 and Figure 2).

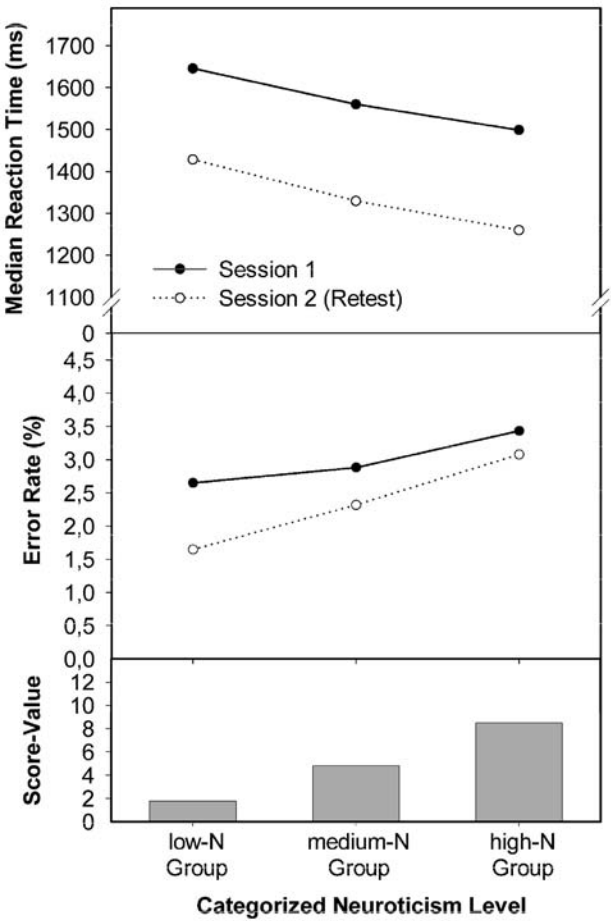

Figure 2. Performance speed (RTM) and accuracy (EP) in the SMACT as a function of neuroticism (N). Participants are separated into three groups according to their *N*-score, so that each group contains 33.3% of the sample.

The ANOVA revealed a significant main effect of N on performance speed [RTMD: $F(1, 64) = 5.1$; $p < .05$; partial $\eta^2 = .07$] and accuracy [EP: $F(1, 64) = 3.8$; $p < .05$; partial $\eta^2 = .06$], indicating that high-N individuals were somewhat faster but committed more errors than low-N individuals. Most interestingly, a significant session × N interaction effect on performance accuracy was obtained [EP: $F(1, 64) = 4.6$; $p < .05$; partial $\eta^2 = .07$] but not on performance speed [RTMD: $F < 1.2$]. This indicates that high-N individuals were less able to profit from practice effects than low-N individuals, such that individual differences did not diminish (which is the typical finding) but even increased after practice. Importantly, the fact that the obtained N-performance relationship was more pronounced in the retesting session substantiates the reliability of the present findings.

In a final step, we examined the relationship between N and performance by looking at the slowest and fastest percentiles of the entire reaction time distribution. Figure 3 depicts the cumulative distributive function (CDF) of reaction times separately for each level of the within-subject factor session (test vs. retest) and the between-subject factor N (low vs. medium vs. high N). The CDFs are vincentized and estimated with the routine developed by Ulrich, Miller, and Schröter (2007). Statistical analyses revealed that high-N individuals differed from low-N individuals even in the fastest percentiles of the CDF [$F(1, 64) = 4.0$; $p < .05$; partial $\eta^2 = .08$], with no interaction between session and N ($F < 1$). Further, it should be noted that the correlational relationship between N and performance speed was highest for the fastest percentile (session 1: $r = -.28^{**}$; session 2: $r = -.23^{*}$) but gradually decreased toward the slowest percentile of the CDF (session 1: $r = -.22^{*}$; session 2: $r = -.08$).

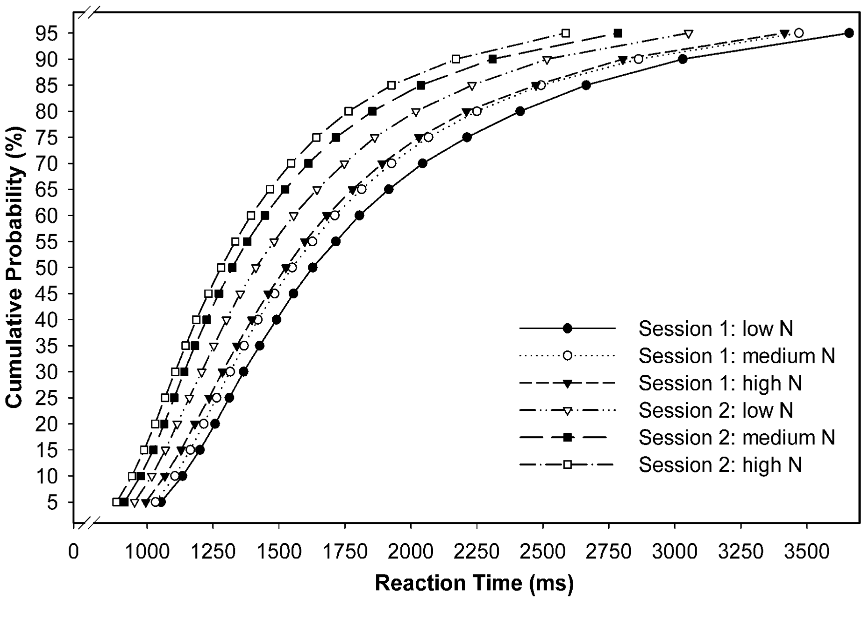

Figure 3. Vincentized cumulative reaction-time distributions (CDFs) as a function of the factors session (test vs. retest) and neuroticism (N) level (low vs. medium vs. high N).

Table 3. Performance in the SMACT in subsamples with low, medium, and high neuroticism score

		N-group	Session 1 (test)			Session 2 (retest)		
			M	*SD*	*SE*	*M*	*SD*	*SE*
1	RTM	low	1754	320	55.7	1512	283	49.3
2		medium	1661	292	50.8	1406	234	40.8
3		high	1588	394	68.6	1320	324	56.4
4	RTMD	low	1645	279	48.5	1428	251	43.7
5		medium	1560	255	44.3	1329	203	35.3
6		high	1498	328	57.2	1260	287	50.0
7	EP	low	2.7	1.8	0.3	1.6	1.2	0.2
8		medium	2.9	1.9	0.3	2.3	2.0	0.4
9		high	3.4	2.9	0.5	3.0	3.8	0.7

Notes. M = mean; *SD* = standard deviation of mean, *SE* = standard error of mean; N is used as a grouping factor forming three groups (low, medium and high N) of $n = 33$ individuals each.

Discussion

The present results can be summarized as follows:

1) High-N individuals responded faster on average but committed more errors than low-N individuals, indicating that they prefer a working style that emphasizes speed at the expense of accuracy.
2) Because response speed increased with error rate in high-N participants, the present data do not suggest that high-N individuals performed less efficiently than low-N individuals.
3) The relationship between N and performance remained stable after practice (i.e., at retest), demonstrating that our finding is not an artificial result but a reliable correlate of neuroticism.
4) The interaction between N at the group level (low vs. high) and session (test vs. retest) provides evidence that high-N individuals benefit less from test–retest practice than low-N individuals, at least when the task contains many items, as was the case in the present study.
5) An inspection of the CDFs of reaction times indicated that the relationship between N and response speed arises not only from the slow percentiles of the RT distribution but also from the fastest percentiles. Actually, higher correlations were found between N and the fastest percentile of the CDF, compared to the slowest percentile.

These results are consistent with reports of a relationship between an anxiety-influenced cognitive style and a shift in the speed-accuracy tradeoff, as shown by studies on test anxiety (e.g., Ashcraft & Kirk, 2001), state/trait anxiety (e.g., Eysenck & Calvo, 1992), and research that examined anxiety-related personality correlates of cognitive performance (e.g., Szymura & Wodniecka, 2003). We extended this relationship to performance in self-paced mental addition and comparison performance. Since high N was associated with a shift of the speed-accuracy tradeoff toward more erroneous responses, it appears inappropriate to conclude that high-N individuals are less efficient in their performance. This discrepancy to previous results may result from the fact that most studies focused on state/trait anxiety, which may have more detrimental effects on performance efficiency than N. It may be argued that high state anxiety is more harmful than high trait anxiety, which, in turn, is more harmful than the "normal-range" anxiousness reflected by high N (Eysenck & Calvo, 1992).

Classical personality theory attributes effects of N on performance to the degree of emotional arousal and its effects on performance. Processing efficiency theory (e.g., Eysenck & Calvo, 1992; Eysenck et al., 2007) extends this classical framework by taking self-regulatory mechanisms into account. The tendency for high-N individuals to become easily aroused when confronted with cognitive task demands may thus be responsible for the reported impairments in performance and the corresponding compensatory strategies, in particular a change in the speed-accuracy tradeoff. In simple RT and very easy choice RT tasks, this tendency may be reflected in the variability of performance: High arousal leads to fast responding; however, occasionally occurring attentional lapses in neurotic individuals produce a certain amount of extremely long responses (Robinson & Tamir, 2005). In tasks like ours, which impose a working memory load, performance effects may be dominated by a change in the individual speed-accuracy tradeoff (Ashcraft & Kirk, 2001; Szymura & Wodniecka, 2003).

We suggest that shifts in the speed-accuracy tradeoff can occur in two ways – or by at least two different mechanisms: First, high levels of tonic arousal (e.g., due to stress) are assumed to affect performance by lowering the threshold for motor execution during speeded performance (Ashcraft & Kirk, 2001; Eysenck & Calvo, 1992). From this perspective, N-related speed-accuracy tradeoffs in self-paced speed tests could stem from a greater time pressure that is internally adopted by high-N individuals, compared to low-N individuals. In two-choice tasks with an easy S–R mapping, this may not result in performance impairments; in more difficult tasks, however, a high pacing rate, internally generated by an individual, should have detrimental effects on accuracy. Second, another possible cause for the N-related individual differences in the speed-accuracy tradeoff may be the large amount of different items (i.e., 148, each presented only four times during the task), which should have prevented participants from establishing item-specific S–R associations. This may be a disadvantage for neurotic individuals, because high-N individuals are assumed to be less effective in encoding and retrieving item-specific information in choice reaction tasks, especially when item-set size is large.

While we believe that our study provides important new data regarding the effects of anxiety-related personality traits on cognitive processing, several limitations must be considered. For example, discrepancies with previous studies could at least partially stem from differences in the sample characteristics. Typically, student samples are used in basic research on personality-related performance differences, which may substantially differ from samples used in clinical research on anxiety-related individual differences. Further, our results are based on performance in a self-paced mental addition task, and other types of speeded-RT tasks may produce different results. Nevertheless, the present results provide support for the notion that working style characteristics of sustained serial-choice performance differ between high- and low-N individuals: High-N individuals appeared to be not globally impaired in their performance, as concluded by others, but tended to emphasize speed at the expense of accuracy. This corroborates the idea that N is related to inadequate self-regulation (Flehmig, Steinborn, Langner, & Westhoff, 2007; Robinson & Tamir, 2005). Our findings also suggest that error proneness in continuous speeded cognitive tasks may be one aspect that is relevant for defining and assessing stable individual differences in cognitive self-regulation ability.

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