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Relations of naturally occurring variations in state anxiety and cognitive functioning

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ABSTRACT

Although effects of anxiety on cognitive performance have been extensively examined, anxiety–cognition relationships are often defined by between-person relationships. The current research investigated the effects of within-person variations in state anxiety on cognitive performance based on measures from three separate sessions in a sample of 1769 healthy adults ranging from 18 to 99 years of age. Some of the adults in the sample exhibited a wide range of state anxiety across the three sessions, whereas others were fairly stable. Although one might have expected that cognitive performance would be low only on sessions in which the level of state anxiety was high, this pattern was not evident in any of five different cognitive abilities (vocabulary, memory, reasoning, spatial relations, or perceptual speed tasks). Instead, one's average level of anxiety was a more important determinant of cognitive performance than one's current level of state anxiety. Specifically, for memory and reasoning abilities, trait anxiety alone related to decreased cognitive function, regardless of state anxiety. For spatial relations and speed abilities, low state anxiety was related to *decreased* cognitive function in participants with high trait anxiety.

1. Introduction

According to Eysenck, Derakshan, Santos, and Calvo (2007), anxiety is defined as, "An aversive emotional and motivational state occurring in threatening situations" (p. 337). The term can be used to describe a chronic condition, in the form of a trait, or a transient experience corresponding to a state. State anxiety refers to an individual's anxiety in a particular situation, while trait anxiety is the tendency to become anxious in many situations and represents a personality dimension of that individual (Eysenck et al., 2007). Prior research has found that high levels of both trait and state anxiety are associated with low levels of cognitive performance (e.g. Eysenck et al., 2007; Salthouse, 2012). These anxiety–cognition relations have been found in both correlational studies, involving comparisons of the cognitive performance of people with different reported levels of anxiety (e.g. Derakshan & Eysenck, 2009, Markham & Darke, 1991, Salthouse, 2012, Sommer, 2014), and in experimental studies in which cognitive performance is evaluated before and after the manipulation of anxiety (e.g. Cumming & Harris, 2001, Leininger & Skeel, 2012, Lupien et al., 1997).

1.1. Anxiety and cognition

According to the processing efficiency theory (Eysenck & Calvo, 1992), anxiety can have competing effects on cognition: worry (an aspect of state anxiety) can impair the working memory capacity of an individual, and simultaneously increase effort for a task resulting in improved performance. The combination of these two processes can produce a peak in performance when the anxiety level is moderate but when tasks are complex the load on working memory will increase and result in poor performance.

1.2. Theory

Much of the prior research examining relations between anxiety and cognition has been based on between-person comparisons in which cognitive performance is examined across different people with differing levels of anxiety (e.g. Salthouse, 2012, Waldstein, Ryan, Jennings, Muldoon, & Manuck, 1997). However, levels of anxiety can also vary within the same individuals and relatively little is known about the relations between within-person fluctuations in anxiety and within-person fluctuations in cognitive performance (e.g. Waldstein et al., 1997). The available evidence is thus insufficient to determine whether people perform at lower levels on days when their self-reported anxiety is high than on days when their self-reported anxiety is low.

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This question is challenging to investigate for a number of reasons. For example, two or more measures of state anxiety and cognition must be available from each participant to allow comparisons of different levels of anxiety in the same individual. In addition, the measures of cognition should be sensitive, and different abilities or domains should be represented to allow the generalizability of the phenomenon to be examined. Most importantly, because participants are likely to have relatively small natural across-session fluctuations in their level of state anxiety, moderately large samples are necessary to identify individuals who have sessions with both low and high levels of anxiety.

1.3. Calculation

Data with these characteristics are available in the Virginia Cognitive Aging Project (VCAP; e.g., Salthouse, 2007, 2009; Salthouse, Pink, & Tucker-Drob, 2008). A unique feature of this project is a measurement burst design in which participants complete a state anxiety questionnaire and perform parallel versions of cognitive tests on three separate sessions within a span of about two weeks. Each of five cognitive ability domains (vocabulary, inductive reasoning, spatial visualization, episodic memory, and perceptual speed) is represented by either three or four separate tests, which can be combined into composite scores to provide sensitive measures of each of the abilities.

Participants in VCAP performed three testing sessions that last between 90 and 120 min each within a period of about two weeks. Each session consisted of the completion of a self-report state anxiety scale and performance of sixteen different cognitive tests. Participants also completed a trait anxiety measure at home between the first and the third session. Most of the individuals had similar values of state anxiety on each session, but some of them had one or more sessions with 'high' levels of anxiety and other sessions with relatively low levels of anxiety. The individuals with highly variable levels of anxiety were of particular interest because cognitive performance on higher state anxiety sessions could be compared with cognitive performance on moderate or low state anxiety sessions.

1.4. Potential outcomes

Evidence suggests that state and trait anxiety might interact with different types of cognitive abilities in unique ways (Bishop, Duncan, Brett, & Lawrence, 2004; Derakshan & Eysenck, 1998; Eysenck et al., 2007; Harris & Cumming, 2003). At least three possibilities can be identified to describe how cognitive performance might vary across 'high' and 'normal' anxiety days. These possibilities can be termed state-dominant, trait-dominant, and state–trait-discrepant. The state-dominant pattern would be apparent if cognitive performance is lower only on the days when the participants report high levels of state anxiety. Because an outcome such as this would resemble the between-person relation between anxiety and cognitive performance, it would be consistent with an interpretation that the same mechanisms linking anxiety to cognition operate across different people at a single point in time and within the same person across different points in time. In other words, since state anxiety produces inefficiency (Eysenck & Calvo, 1992), there would be a direct correlation between high state anxiety and low cognitive scores, regardless of the individual's average level of anxiety.

According to the Attentional Control Theory, consistent anxiety impairs a person's ability to ignore distractors and thereby diminishes performance, especially when tasks are demanding (Eysenck et al., 2007). The consistent nature of trait anxiety might impair one's inhibition even if they are not anxious in the moment. Hence, a pattern in which cognitive performance in the variable individuals is low even on days in which they have low levels of anxiety can be characterized as 'trait-dominant' because performance is more closely related to the average state, or trait, level of anxiety than by the level of state anxiety on a given session. If people with varying (and therefore higher) levels of trait anxiety perform worse than people with stable (and therefore lower) trait anxiety regardless of state anxiety level, the relevant factor varying with cognitive functioning may not be the individual's current level of state anxiety, but his or her trait anxiety.

Some researchers have suggested that performance on certain tasks may be optimized if the person's mood state is consistent with their mood trait (Tamir, Robinson, & Clore, 2002). This leads to a third possible outcome that can be designated as 'state–trait-discrepant' in that the major factor associated with cognitive performance may not be one's current level of state anxiety or trait anxiety, but instead could be the discrepancy between the individual's trait level of anxiety and his or her reported state anxiety level on a given session. Because the variable participants will tend to have higher average levels of anxiety than the stable participants, the expectation from this perspective is that variable participants would have lower cognitive performance on the session in which his or her self-reported state anxiety is lowest because the discrepancy from their trait level of anxiety will be highest.

2. Materials and methods

2.1. Participants

Participants were recruited through advertisements, flyers, and referrals from other participants. They reported to the laboratory on three separate days within about two weeks. Informed consent was obtained from each participant at the beginning of the first session. Only participants with complete data from all three sessions were included in the current study.

2.2. Preliminary analyses

In order to determine what should be considered high levels of anxiety in this sample, an initial analysis examined the relation between anxiety and cognitive performance across different people on the same session. There was a significant decline in cognitive performance for individuals with the state version of the State–Trait Anxiety Inventory (STAI-S; Spielberger, 1983) scores greater than 36. Therefore, in the main analyses, participants of interest were assigned to the variable group if they had at least one session with anxiety scores above 36 in the between-person comparison (because anxiety scores from this range were associated with significantly lower cognitive ability), and at least one session with anxiety scores in the "normal" range in which the average cognitive performance was high. This selection allowed for a direct comparison between cognitive performance on high- and low-state anxiety days.

Because some across-session fluctuation in cognitive performance would be expected in everyone, individuals with low levels of across-session variability in state anxiety were included in addition to the individuals with high across-session variability in order to determine whether variable participants' performance when they report low anxiety is similar to that of the low-variation (stable) group.

2.3. Group selection

The variable group consisted of participants whose highest state anxiety score was at least 36 and their lowest state anxiety score was at least 19 points below their highest state anxiety score. (Given that the minimum score on the STAI-S was 20, the actual minimum value in the high-anxiety session in the variable group was 39.) The stable comparison group consisted of participants whose highest state anxiety score was less than 36, and who had a difference between the highest and lowest state anxiety score of less than 20. For example, an individual with state anxiety scores of 30, 27, and 23 would have a high-low difference of 7 (i.e., session 1 score of 30 minus session 3 score of 23), and would be assigned to the stable group. In contrast, an individual with state anxiety scores of 28, 57, and 33 would have a high-low difference of 29 (i.e., session 2 score of 57 minus session 1 score of 28), and would be assigned to the variable group. Individuals who did not fit within either of these categories (N = 793) were not included in the major analyses, but were used in examining the between-person relations of anxiety and cognition. Descriptive variables for the stable (N = 1631) and variable (N = 138) groups are presented in Table 1.

2.4. Measures

2.4.1. State anxiety

At the beginning of each session, participants completed the state anxiety subscale of the STAI. The STAI-S consists of 20 statements with half of the statements representing positive emotions and the other half representing negative emotions. Participants rated their agreement with the item "at this moment" on a scale ranging from 1 to 4. The coefficient alphas for sessions 1, 2, and 3 were .89, .90, and .90, respectively.

2.4.2. Cognitive functioning

In each of the three sessions the participants performed 16 cognitive tests representing 5 cognitive abilities; Vocabulary, Episodic Memory (memory), Inductive Reasoning (reasoning), Spatial Visualization (space), and Perceptual Speed (speed). The tests of vocabulary were multiple-choice synonym and antonym tests, a picture vocabulary test, and a provide-the-definition vocabulary test. Memory was assessed with word recall, paired associates, and logical memory tests. Reasoning was assessed with matrix reasoning, series completion, and letter set tests. The spatial visualization ability was assessed with tests of spatial relations, paper folding, and form boards. Perceptual speed was assessed with digit symbol, pattern comparison, and letter comparison tests. The tasks are described in more detail in previous publications (Table 1 in Salthouse, 2007) including information about the reliabilities and validities in the form of loadings on their respective ability factors (Salthouse, 2007, 2009; Salthouse et al., 2008).

Parallel versions of the tests were administered on each session in the same order for all participants to avoid confounding pre-existing individual differences with how the participants were treated. Difficulty level of the different versions was equated using the procedure described in Salthouse (2007). Specifically, data from a sample of 90 adults who performed the task versions in counterbalanced order were used to construct regression equations relating performance on different versions to one another. The parameters of these equations were then used to adjust the scores of each participant's scores on each version of the tests.

Table 1
Means (and standard deviations) of characteristics of the stable and variable participants.

	Stable	Variable	Cohen's *d*
N	1631	138	N/A
Age	53.3 (17.6)	52.5 (18.8)	0.05
Sex	0.63 (0.48)	0.68 (0.47)	−0.10
Health	2.1 (0.9)	2.3 (1.0)	−0.25
Education	15.9 (2.7)	15.6 (2.7)	0.10
MMSE	28.5 (1.8)	28.0 (2.3)	0.26*
Scaled scores			
Word recall	11.9 (3.2)	11.4 (3.6)	0.19
Logical memory	11.6 (3.1)	11.2 (3.4)	0.14
Digit symbol	11.3 (2.8)	10.9 (3.1)	0.14
Vocabulary	12.5 (3.1)	12.3 (3.3)	0.05
State anxiety			
Session 1	25.3 (4.3)	34.0 (11.1)	−1.04*
Session 2	25.2 (4.5)	40.2 (14.9)	−1.36*
Session 3	24.8 (4.4)	42.4 (14.0)	−1.70*
Std. dev.	2.5 (1.8)	13.7 (3.7)	−3.03*
Trait anxiety	32.0 (8.1)	42.1 (12.2)	−0.98*

Note: d values refer to effect sizes, with * indicating whether the difference was significant in an independent-groups t-test ($p < .01$). Sex was coded 0 for males and 1 for females. Health was a self-rating on a scale ranging from 1 for "excellent" to 5 for "poor". MMSE refers to the Mini Mental State Exam (Folstein et al., 1975). Scaled scores are adjusted for age and have means of 10 and standard deviations of 3 in the nationally representative normative samples.

Because four of the tests (provide-the definition vocabulary, digit symbol, word recall, and logical memory) were based on the Wechsler test batteries (Wechsler, 1997a, 1997b), scores on those tests were converted to age-adjusted scaled scores to compare the sample to the nationally representative normative sample. It is apparent in Table 1 that the mean scaled scores averaged .5 standard deviations or more above the mean values in the general population.

2.4.3. Other measures

Table 1 also contains scores on the Mini-Mental State Exam (MMSE; Folstein, Folstein, & McHugh, 1975), which was administered on the first session. Scores below about 24 are often considered indicative of probable dementia, but the means in both groups were above 28, and over 90% of the participants in each group had scores of 24 or more.

The participants also completed several questionnaires at home between the first and third sessions, and relevant scores in the two groups are presented in Table 1. The STAI Trait parallels the STAI State questionnaire with 20 questions rated on a scale of 1–4. However, participants rate their feelings "generally" rather than "at this moment" (Spielberger, 1983).

2.5. Analysis plan

The scores in each cognitive test were converted into z-scores to express performance on all of the tests in the same units, and the z-scores averaged for tests representing each of the cognitive abilities to form composite scores. In order to minimize influences associated with age or sex, all analyses were conducted on residual composite scores created by partialling the effects of age and sex from the composite scores.

Mixed effects analyses of variance (ANOVA) with group (stable vs. variable) as a between-participant factor, and session (high- vs. low-anxiety) as a within-participant factor were conducted. The initial analysis focused on the state anxiety scores in order to confirm that the variable group had a greater difference between the high- and low-anxiety sessions than the stable group. The remaining analyses were conducted on residual composite cognitive scores.

The state-dominant outcome would be supported by an interaction in the direction of lower performance for the variable group than for the stable group, primarily on high-anxiety sessions. The trait-dominant outcome would be supported by a main effect of group but no interaction. Finally, an interaction in the direction of lower cognitive performance on low anxiety sessions for the variable group than for the stable group would be consistent with the state–trait-discrepant interpretation.

3. Results

An initial analysis examined relations on the first session between state anxiety and performance in the five cognitive domains in the total sample of 2562 participants. Because of prior reports of non-linear relations between anxiety and cognition (e.g. Salthouse, 2012), the sample was divided into quintiles based on state anxiety scores.

Cognitive performance was relatively stable across the first three quintiles, and was much lower in the highest quintile, corresponding to state anxiety scores above 36. Analyses of variance on the age- and sex-adjusted cognitive composite scores on session 1 revealed that the quintile differences were significant ($p < .01$) for each of the abilities (i.e., all F's > 5.3, all partial eta^2 > .008).

3.1. Stable and variable group differences

Table 1 indicates that stable and variable groups were similar in their levels of cognitive functioning as indicated by the scaled scores on the four standardized tests. It can also be seen that the variable group, compared to the stable group, had significantly higher trait anxiety and state anxiety on each session, and also higher standard deviations of state anxiety across sessions.

The group X session ANOVA on the state anxiety scores by session indicated significant main effects of group (stable = 25.1, variable = 38.9), significant main effects of session (1 = 29.7, 2 = 32.7, and 3 = 33.6), and a significant interaction in the direction of larger session differences in the variable group than in the stable group.

State anxiety scores on the sessions in which the participants in the variable and stable groups had their lowest and highest levels of state anxiety were also compared. An ANOVA revealed that F ratios were greater than 1500 for the group main effect, the session main effect, and the group X session interaction. Although all differences were highly significant, the difference between the stable and the variable group was smaller (*Cohen's* $d = -1.17$) for the low-anxiety session than for the high-anxiety session (*Cohen's* $d = -3.34$). Importantly, the average anxiety for the variable group in the low-anxiety session was within the range associated with normal cognition in the between-person comparisons.

The primary analyses compared cognitive performance in the stable and variable groups on their highest and lowest anxiety sessions. Means and standard errors of the age- and sex-adjusted residual cognitive scores are portrayed in Fig. 1.

Table 2
F ratios (and partial eta^2) for group (stable or variable) X session (low or high anxiety) ANOVAs on age- and sex-adjusted cognitive composite scores.

	Group	Session	Group X session
Vocabulary	2.05 (.001)	0.12 (.000)	1.75 (.001)
	0.77 (.000)	1.07 (.001)	0.01 (.000)
Reasoning	21.06 (.012)*	0.11 (.000)	1.68 (.001)
	10.00 (.006)*	0.39 (.000)	0.80 (.000)
Space	13.56 (.008)*	5.89 (.003)	16.61 (.009)*
	6.31 (.004)*	0.53 (.000)	1.57 (.001)
Memory	14.19 (.002)*	0.06 (.000)	1.57 (.001)
	9.04 (.005)*	0.00 (.000)	1.05 (.001)
Speed	6.74 (.004)*	3.39 (.002)	11.90 (.007)*
	1.53 (.001)	0.31 (.000)	7.65 (.004)*

Note: Values in the second row are ANCOVAs with trait anxiety as a covariate.
* $p < .01$.

Results of group X session ANOVAs for each cognitive domain are summarized in Table 2, along with results of an analysis of covariance in which trait anxiety was used as a covariate in the analyses. Inspection of Fig. 1 reveals that the means were significantly higher in the stable group than the variable group for all cognitive domains except vocabulary. Most interestingly, the interaction of group and session was significant ($p < .01$) for space and speed, and in both cases it was in the direction of the participants in the variable group exhibiting lower cognitive performance on the session with the lowest reported anxiety. As discussed above, these results are consistent with a trait-dominant outcome for memory and reasoning abilities and a state–trait-discrepant outcome for space and speed abilities.

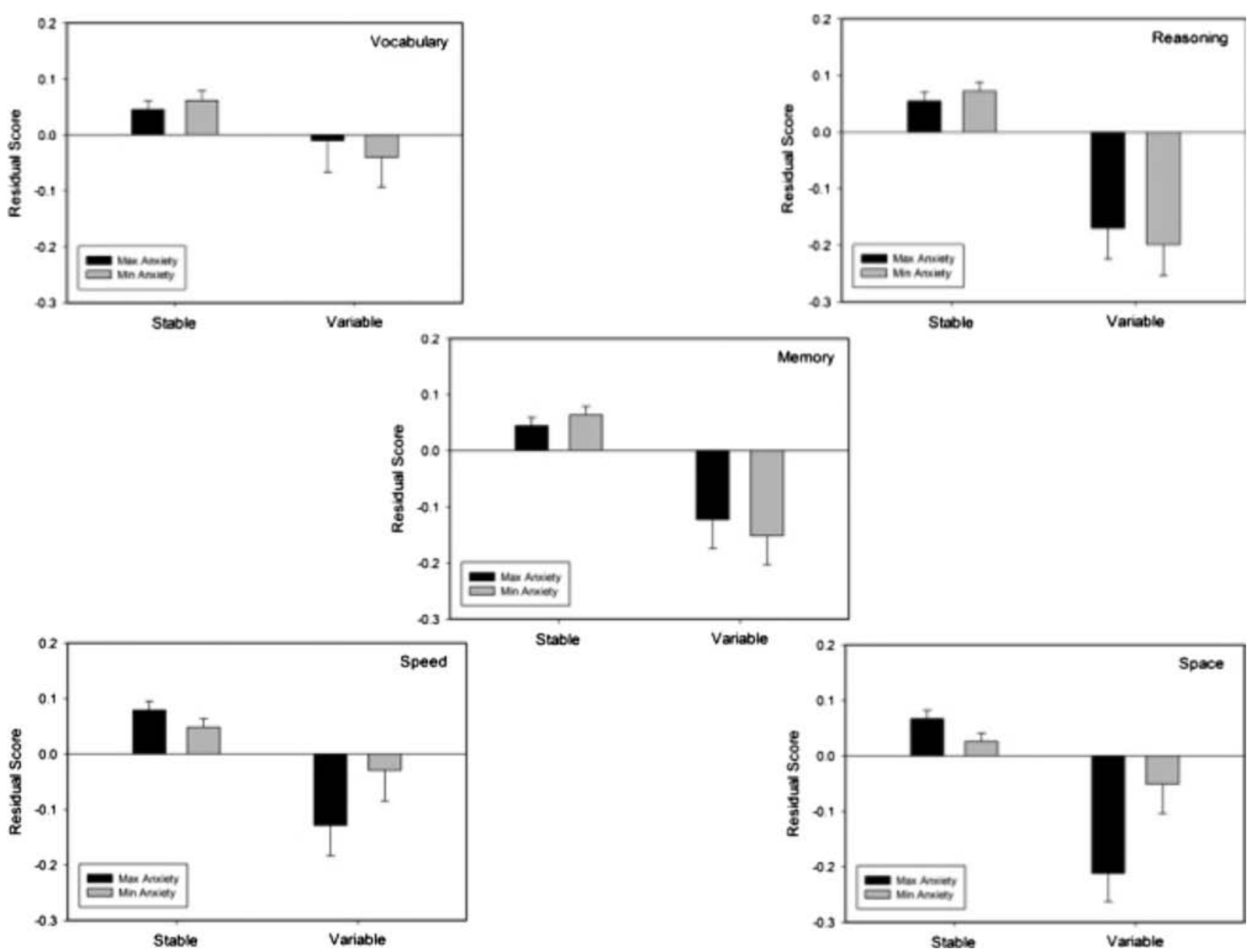

Fig. 1. Means (and standard errors) of age- and sex-adjusted residual cognitive scores in high and low anxiety sessions in stable and variable groups.

4. Discussion

A novel contribution of the current study was examination of the relationship between state anxiety and cognition within the same individuals, made possible by the measurement burst design implemented in the Virginia Cognitive Aging Project. That is, VCAP participants completed the state anxiety questionnaire and performed parallel versions of the same cognitive tests on three separate sessions. Most participants had relatively stable state anxiety levels across sessions, but about 8% of them exhibited considerable variability, with very high anxiety scores (typically associated with low cognitive scores in between-person comparisons) in some sessions, and scores in the range associated with normal cognitive scores in other sessions. The primary focus in this project was the cognitive performance of individuals in the variable group on their low- and high-anxiety sessions. In particular, we were interested in determining whether an individual's cognitive performance was in the normal range when his or her self-reported state anxiety was also in the normal range.

Our major finding was that this was not the case, and instead cognitive performance in the variable group was lower than performance in the stable group even on days when their self-reported anxiety was in the normal range. There was therefore no evidence for a state-dominant pattern in which level of cognitive performance varied according to one's current level of state anxiety. Importantly, the results of the analyses were very similar when trait anxiety was included as a covariate, and thus the findings are not simply attributable to different overall levels of anxiety in the two groups.

The effects of trait and state anxiety varied according to the type of cognitive ability. In two of the cognitive domains, reasoning and memory, the results were consistent with a trait-dominant pattern as cognitive performance in the variable group was much lower than that in the stable group on both high- and low-anxiety sessions. For the measures of spatial visualization and perceptual speed abilities the results were more consistent with a state–trait-discrepant pattern in that performance of the variable group was lower in the low-anxiety sessions than in the high-anxiety sessions. However, there were no significant differences between variable and stable groups for vocabulary, regardless of the level of state anxiety.

The lack of group X session interactions for the domains of memory and reasoning indicated that variable participants performed at lower levels than stable participants even on days when they reported relatively low levels of anxiety. For these ability domains it appears that the primary influence on one's level of cognitive functioning is the individual's average, or 'trait-level' anxiety, and not his or her current level of state anxiety.

The significant interactions of group X session with the measures of spatial visualization and perceptual speed were in the direction of lower levels of performance in the variable group on the session in which their state anxiety was within the normal range. Because the variable participants (who had higher average levels of anxiety than the stable participants) performed worse on days when their state anxiety was in the normal range, this pattern is consistent with the state-discrepant outcome.

A possible explanation for the state–trait-discrepant outcome is that the inconsistency between a person's trait and state anxiety is unconsciously associated with uncertainty that requires considerable cognitive resources, and reduces the amount available for the performance of cognitive tasks (see Tamir et al., 2002 for a similar interpretation based on discrepancies in affect). The differential effects across cognitive domains may be attributable to the greater sensitivity of speed and spatial tasks to fluctuations in the availability of cognitive resources either because of the requirement for rapid responses in the case of speed, or because of the unfamiliar nature of the tasks in the case of space.

It has been proposed that even mild forms of anxiety increase susceptibility of attentional bias (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van Ijzendoorn, 2007). Since this analysis did not include a clinical sample of participants, the levels of anxiety were not as high as cut off scores used in some of the literature (e.g. Derakshan & Eysenck, 2009). This may account for the relatively small effect sizes for some of the analyses. However, considering that anxiety was not manipulated and the cut off scores were based on low cognitive functioning in the total sample rather than on clinical levels of anxiety, the results may apply to a higher proportion of the population.

5. Conclusions

In sum, the results of this study indicate that while between-person comparisons often reveal strong relations between state anxiety and level of cognitive performance, these relations are not apparent in within-person comparisons. Instead, the findings suggest that cognitive performance is more strongly related to one's chronic level of anxiety than to the level of state anxiety at any given time. In this respect, it appears that trait trumps state.

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