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Test Anxiety, Working Memory, and Cognitive Performance:

Supportive Effects of Sequential Demands

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Abstract

Substantial evidence suggests that test anxiety is associated with poor performance in complex tasks. Based on the differentiation of coordinative and sequential demands on working memory (Mayr & Kliegl, 1993), two studies examined the effects of sequential demands on the relationship between test anxiety and cognitive performance. Both studies found that high sequential demands had beneficial effects on the speed and accuracy of the performance of test-anxious participants. It is suggested that the more frequent memory updates associated with high sequential demands may represent external processing aids that compensate for the restricted memory capacity of individuals with high test-anxiety.

Keywords: test anxiety, cognitive performance, working memory

Introduction

High levels of test anxiety are known to cause decrements in cognitive performance (Hembree, 1988). The negative effects of test anxiety on performance, however, are moderated by task complexity, as highly test-anxious persons often show performance decrements only in complex tasks (for recent reviews, see Mueller, 1992; Zeidner, 1998). One of the most influential theories aiming to explain this relationship was formulated by M. Eysenck (1979, 1985; Eysenck & Calvo, 1992). According to Eysenck, restrictions in working memory capacity are responsible for the decrements in the cognitive performance of highly test-anxious individuals because, in test situations, these individuals encounter task-irrelevant thoughts such as worries and concerns about self-evaluative aspects of failure which partially occupy working memory capacity. In easy tasks, the remaining memory capacity may suffice to fulfill task requirements. In complex tasks, however, it may not. Consequently, high-anxious individuals will show performance decrements primarily in complex tasks.

According to Baddeley (1986), the working memory system is conceptualized as consisting of various modality-specific, active storage subsystems (e.g., a "phonological loop" for maintaining acoustical input and a "visuo-spatial sketch pad" for storing visual input) and a supervisory attentional system called the "central executive." The latter coordinates the information-maintenance processes within and between the various subsystems. Thus, in contrast to conventional concepts of short-term memory (e.g., Atkinson & Shiffrin, 1968), Baddeley's working memory system encompasses both storage and processing facilities.

Research on test anxiety and cognitive performance in complex tasks supports Baddeley's conceptualization of working memory. For example, Darke (1988) measured digit span (indicative of storage capacity) and reading span (indicative of both storage and processing capacity). High-anxious individuals displayed lower values than low-anxious individuals in both digit and reading span. However, the difference in reading span was considerably greater. Similar results were obtained by MacLeod and Donellan (1993) and Derakshan and Eysenck (1998). In both studies, participants were asked to perform a complex verbal reasoning task under conditions of low or high concurrent memory load.

In both conditions, participants had to memorize a string of six digits, either six zeros (low memory load) or six random digits (high memory load). In the high memory-load condition, solving the complex reasoning task while rehearsing the digit string charged the working memory system with both storage demands and coordinative demands. Results of both studies showed that the response times of high-anxious participants increased more than those of low-anxious individuals.

In sum, these results indicate that high-anxious individuals' deficits in cognitive performance are probably due to restrictions in both storage *and* processing capacity of the working memory system. If this is case, it may open new ways of exploring the role that working memory plays in anxiety-related decrements in cognitive performance. With regard to the processing component, in particular, it should be possible to identify not only task characteristics that impair performance (because they tax restricted processing capacity), but also task characteristics that enhance performance (because they compensate for restricted processing capacity).

This idea, however, requires a more differentiated concept of task complexity. A good candidate for a theory-based concept of task complexity is the distinction between coordinative complexity and sequential complexity (Mayr & Kliegl, 1993). *Coordinative complexity* refers to the fact that many cognitive tasks require information to be processed while simultaneously storing the results of previous processing steps so that this intermediately stored information can be integrated with later processing results. Coordinative complexity varies with the amount of different information to be maintained during processing. The central features of coordinative complexity are the coordination of information maintenance with current information processing and the regulation and monitoring of the flow of information between interrelated processing steps. *Sequential complexity*, in contrast, refers to the number of successive and independent processing steps. In tasks with high sequential complexity, working memory contents are frequently updated without increasing the amount of information exchanged between processing steps. Thus, sequential complexity does not make additional demands on the storage components of the working memory system. On the contrary, by providing frequent prompts for memory contents to be updated, sequential demands may even relieve the working memory system from information-maintenance processes such as regulating and monitoring the refreshing, changing, and updating of memory contents. If so, sequential complexity could have beneficial effects on performance in coordinatively complex tasks--particularly for high-anxious individuals who, due to task-irrelevant thoughts, have reduced working memory capacity.

However, whereas the effects of coordinative complexity on the performance of anxious individuals have been well established, no study has yet provided a systematic investigation of test anxiety and sequential complexity. The aim of the present studies was to provide a first such investigation by exploring memory performance in a task with high coordinative complexity under low and high sequential demands.

Study 1

Method

Participants

A sample of 24 students (18 female) was recruited at the Free University of Berlin according to the selection procedure outlined below. Average age was 27.0 years (*SD* = 6.7). All participants volunteered in exchange for two hours of extra course credit.

Procedure

Test anxiety. Students were recruited during class for an experiment on "memory and attention." Students who indicated interest in participating filled out the German Test Anxiety Inventory (TAI-G) devised by Hodapp (1991, 1995). The TAI-G is a 30-item self-report measure of the tendency to experience anxiety in test situations (e.g., "I worry about possible mischief"). With a four-point answer scale from *Almost never* (1) to *Almost always* (4), TAI-G scores have a potential range of 30-120. The TAI-G has demonstrated high reliability (Cronbach's alpha ≥ .91) and substantial validity (Hodapp, 1991, 1995; Musch & Bröder, 1999). From the participants who had indicated interest in the experiment, we selected 12 participants with scores in the upper third and 12 participants with scores in the lower third of the distribution of TAI-G scores, following preliminary TAI-G norms for university students (V. Hodapp, personal communication, October 14, 1995).[1] The mean of TAI-G scores in the low test-anxiety group was M = 52.6 (range = 46-60) and in the high test-anxiety group M = 88.3 (range = 75-106).

Counting task. To assess memory performance in a task with high coordinative complexity, we used the three-target version of the counting task developed by Dutke (1997). The counting task is computer-administered. In the center of a computer monitor, a list consisting of ten (randomly chosen) two-digit numbers is displayed for eight seconds. After a pause of two seconds, the next list of numbers is displayed. Overall, 40 lists are presented. The participants' task is to search each list for the presence of one of three targets (the numbers 16, 38, and 67), count the occurrence of each target, and provide a special response when a target is displayed for the third time, as indicated below. Thus, participants have to manage three mental counters, one for each target.

At the beginning of the counting task, the mental counter for each target is zero. When participants detect a target, the counter for this target is increased by one. Each time a list is presented, participants have to provide a response as to whether or not they see a target for the third time. If a list contains no target, or if a target appears for the first or second time only, participants have to press a key marked "No." However, if a target appears for the third time, participants have to press the respective key for this target (i.e., a key marked "16", "38", or "67"). Moreover, participants have to reset their mental counter for this target to zero (so that the next appearance of this target will again be counted as its first appearance). The mental counters for the other two targets remain unchanged. Previous research with the three-target version of the counting task has demonstrated that this task has high coordinative complexity and puts high demands on participants' working memory capacity (Dutke, 1997).[2] The complete counting task lasted 400 seconds.

Sequential demands. The advantage of the counting task is that it allows for sequential demands to be varied independently of coordinative demands simply by manipulating the frequency with which targets appear (Dutke, 1997). In the present study, two conditions of sequential demands were implemented. In the low sequential demands condition, 14 out of 40 lists (35%) contained a target. In the high sequential demands condition, 27 out of 40 lists (68%) contained a target. Sequential demands were varied as a between-participants factor. Within anxiety groups (high versus low test anxiety), participants were randomly allocated to sequential demands conditions. All experimental sessions were held individually.

Results

The counting task allows for the assessment of two performance measures: speed (response times) and accuracy (number of counting errors).[3] First, we examined speed by calculating a two (test anxiety [TA]) × two (sequential demands) between-participants ANOVA on mean response times. Whereas both main effects were nonsignificant (TA: $F < 1$; sequential demands: $F[1, 20] = 3.25$, *ns*), the interaction of TA and sequential demands was highly significant (Table 1). To further explore this interaction effect, post hoc tests were calculated using Fisher's least significant difference (LSD) tests (i.e., multiple *t* tests between all pairs of groups). Results suggested that high sequential demands had a positive effect on the speed of high TA participants' performance. High TA participants under high sequential demands responded significantly faster than (a) high TA participants under low sequential demands and (b) low TA participants under high sequential demands. In addition, under low sequential demands, high TA participants responded significantly slower than low TA participants.

Second, we examined the number of counting errors to check whether the effect observed in the response times was due to a speed-accuracy trade-off, such that participants who responded faster (higher speed) made more counting errors (lower accuracy). However, the number of counting errors followed the same pattern as the response times. Again, the main effects were nonsignificant, both Fs < 1, and the interaction was significant (Table 1). Post hoc tests (Fisher's LSD) indicated that high sequential demands also had a positive effect on the accuracy of the high TA participants' performance: High TA participants under high sequential demands made significantly fewer counting errors than (a) high TA participants under low sequential demands and (b) low TA participants under high sequential demands.

Discussion

Overall, the results showed a clear pattern: In a task with high coordinative complexity, high sequential demands had a positive effect on both the speed and accuracy of the performance of highly test-anxious participants. Under high sequential demands, participants with high test anxiety responded faster and made less errors than participants with low test anxiety. These findings suggest that sequential demands may enhance the cognitive performance of test-anxious individuals working on a coordinatively complex task. Despite these clear-cut results, however, there remained the question of whether these findings are reliable. First, due to the lack of previous studies on the subject matter, Study 1 was rather exploratory in nature. Moreover, because of the small sample size, post hoc difference tests were calculated using Fisher's LSD tests. While these tests have the greatest statistical power to detect potential differences (Klockars & Sax, 1986), they do not adjust for a potential inflation of alpha error. Finally, the loss of information due to the dichotomization of test-anxiety scores may well be criticized (Cohen, 1983).

Therefore, a second study was conducted to replicate the interaction effect of test anxiety and sequential demands found in Study 1, using test anxiety as a continuous variable (instead of using extreme groups). Consequently, we translated the pattern of mean differences found in Study 1 to correlational hypotheses, thus arriving at the following expectations: If high sequential demands have supportive effects on performance for high-anxious participants, we can expect to find *differences* between the correlations of test anxiety and response time depending on the sequential demands condition to the effect that the correlation between anxiety and response time should be negative under high sequential demands, and positive under low sequential demands. To rule out a speed-accuracy trade-off, a parallel effect should be obtained for the number of counting errors.

Study 2

Method

Participants

A sample of 30 students (25 female) was recruited at the Free University of Berlin by postings announcing an experiment on "memory and attention." Average age was 25.9 years (*SD* = 8.1). All participants volunteered in exchange for two hours of extra course credit.

Procedure

Test anxiety. Upon arrival in the laboratory, participants filled out the German Test Anxiety Inventory (TAI-G; Hodapp, 1991). Mean TAI-G score of the sample was 66.5 (*SD* = 15.2, range = 40-90).

Sequential demands. The counting task was the same as in Study 1, except for two changes introduced to increase statistical power. First, to augment the difference between low and high sequential demands, the number of targets in the low sequential demands condition was reduced to 10 out of 40 lists (25%) containing a target. The high sequential demands condition was unchanged with 27 out of 40 lists (68%) containing a target. Second, to decrease error associated with individual differences in performance, sequential demands were implemented as a within-participants factor. Half of the participants worked on the counting task first under low sequential demands and then under high sequential demands; for the other half of participants, it was the other way round. Sequence was balanced across participants, and participants were randomly allocated to sequence conditions.

Results

First, we examined response times by calculating a one-way repeated measures ANOVA with sequential demands as a within-participants factor and test anxiety (TA) scores as a continuous covariate. As in Study 1, the main effects associated with test anxiety and sequential demands were nonsignificant, both *F*s < 1, whereas the interaction of test anxiety and sequential demands was again significant, $F(1, 28) = 4.75$, $p < .05$. In line with our hypotheses, sequential demands had supportive effects on performance speed in participants with high TA scores (Table 2): Under low sequential demands, the correlation between TA and response times was positive; under high sequential demands, it was negative. As predicted, the difference between these two correlations was significant. To further explore the data pattern, difference scores between low and high sequential demands were calculated with *d* = mean response time (high sequential demands) – mean response time (low sequential demands). Correlating these difference scores with TA scores resulted in a correlation of $r = -.38$, $p < .05$, indicating that the more test anxiety individuals reported, the greater the reduction in mean reaction times under high sequential demands relative to low sequential demands. Consequently, highly test-anxious participants profited more from high sequential demands than less test-anxious participants.

Second, we inspected the number of counting errors to investigate whether this result was due to a speed-accuracy trade-off. Like the response times, counting errors were subjected to a one-way repeated measures ANOVA with sequential demands as a within-participants factor and TA scores as a covariate. Again, we found a parallel pattern for the number of counting errors. As in Study 1, both main effects were nonsignificant (TA: $F < 1$; sequential demands: F[1,28] = 3.30, *ns*). This time, however, the interaction effect of TA and sequential demands was also nonsignificant, $F(1, 28) = 2.20$, *ns*. Still, the pattern of results supported our predictions, even though the associated p values did not reach standard levels of significance (see Table 2). Overall, high TA participants also profited from higher sequential demands with respect to counting errors: The correlation between TA and counting errors was negative under high sequential demands, but positive (or close to zero) under low sequential demands. As with reaction times, difference scores for counting errors were computed and correlated with test anxiety. The resulting correlation pointed in the direction of our predictions, but was nonsignificant, $r = -.27$, *ns*.

Discussion

As in Study 1, we found a significant interaction effect of test anxiety and sequential demands on response times such that high-anxious participants responded faster than low-anxious participants under high sequential demands relative to low sequential demands. Moreover, we again found that this effect was not due to a speed-accuracy trade-off. Even though the interaction effect for counting errors was nonsignificant in Study 2, a speed-accuracy trade-off could be ruled out as an alternative explanation because the difference between correlations was in the predicted direction (i.e., in the same direction as in the correlations with response times). Overall, the pattern of correlations found in Study 2 followed closely the pattern of mean differences found in Study 1 (cf. Table 1 with Table 2). Thus, the supportive effect of sequential demands on cognitive performance of high-anxious individuals was replicated.

Even though our hypotheses referred to the difference of correlations, not to their absolute size, one might criticize that the correlations in Study 2 between test anxiety and performance were rather low, particularly when compared to the mean differences found in Study 1. A potential explanation for this result may be variance restrictions in Study 2. In Study 1, test anxiety scores varied between 46 and 106. In Study 2, they varied only between 40 and 90. Thus, high-anxious participants were somewhat underrepresented in Study 2. Because variance restriction may result in covariance restriction, the correlations in Study 2 may be attenuated.

General Discussion

In sum the present studies demonstrated that, when exploring the role of working memory in anxiety-related performance decrements, it may be useful to differentiate between coordinative and sequential complexity (Mayr & Kliegl, 1993). While coordinative demands have repeatedly been shown to aggravate anxiety-related decrements in memory performance (e.g., Derakshan & Eysenck, 1998; MacLeod & Donellan, 1993), the present studies found that sequential demands had beneficial effects on the cognitive performance of test-anxious individuals.

Processing characteristics associated with high sequential demands may provide a potential explanation of these effects. In tasks with high sequential demands, participants are prompted to update their working memory contents more often than in tasks with low sequential demands. Thus, high sequential task demands may partially relieve participants' working memory from control processes such as updating or refreshing. As those control processes require memory capacity, highly test-anxious individuals--having reduced memory capacity due to task-irrelevant thoughts--may profit from these task-related external prompts.

Whereas the present findings show that differentiating coordinative and sequential demands may be a fruitful concept for research on test anxiety and memory performance, some questions remain. First, the sample sizes of both studies were rather small and consisted mainly of female participants. Consequently, attempts to replicate our findings with larger samples balanced for gender are desirable in subsequent studies. Second, it may be that high-anxious individuals run into problems with still higher levels of sequential demands than those implemented in the present studies. Third, previous research has shown that increased sequential demands are usually associated with reduced cognitive performance, though to a much smaller degree than coordinative demands (Dutke, 1997; Mayr & Kliegl, 1993). Whereas this may encourage researchers to pay more attention to individual differences such as test anxiety, the above cannot explain why low-anxious participants do not profit from sequential demands. Possibly, low test-anxious individuals are engaging in self-initiated, active memory updates in all conditions and therefore do not profit from external prompts. Thus, future research will have to tackle the question of which differential mechanism is responsible for the finding that high sequential task demands are only beneficial for high-anxious individuals.

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Footnotes

[1]Students who did not qualify for participation had the opportunity to participate in another, similar experiment to obtain extra course credit.

[2]An English manuscript describing the research method and main results of Dutke (1997) may be obtained from the first author upon request.

[3]In the counting task, four types of counting errors may occur, namely (a) a "no" response when a target number appears for the third time, (b) a "yes" response when a target appears for the first or the second time only, (c) a "yes" response when the list contains no target, and (d) no response at all. Preliminary analyses indicated no test-anxiety effects with type of counting error. Thus, all types of counting errors were collapsed. To account for the differences in number of targets between low and high sequential demands, the percentage of counting errors was used in all analyses instead of the absolute number of counting errors.

Table 1

Study 1. Interaction of Test Anxiety and Sequential Demands on Performance: Group Means

	Sequential demands				
	Low		High		
Performance measure	Low TA (n = 6)	High TA (n = 6)	Low TA (n = 6)	High TA (n = 6)	$F(1, 20)$
Mean response time (s)	4.98_{a}	$5.60_{a,b}$	5.24_{c}	$4.65_{b,c}$	9.88**
Relative number of counting errors	3.71	4.81_{a}	4.88_{b}	$2.14_{a,b}$	4.83*

Note. N = 24. Sequential demands is a between-participants factor. TA = test anxiety. $F(1, 20)$ = F value associated with the interaction effect of test anxiety and sequential demands. Within rows, means with the same subscript differ significantly at $p < .05$ (Fisher's LSD tests).

*$p < .05$. **$p < .01$.

Table 2

Study 2. Interaction of Test Anxiety and Sequential Demands on Performance: Means and Correlations With Test Anxiety

	Sequential demands				
	Low		High		
Performance measure	*M*	*r*(TA)	*M*	*r*(TA)	*z*
Mean response time (s)	5.39	.14	4.65	–.21	1.97*
Relative number of counting errors	3.65	.06	4.90	$–.24^{+}$	1.36^{+}

Note. $N = 30$. Sequential demands is a within-participants factor. TA = test anxiety. z = z value associated with the difference between the two *r*s(TA), following the formula of Meng, Rosenthal, and Rubin (1992) for testing differences between two dependent correlations.
$^{+}p < .10$. $^{*}p < .05$. One-tailed tests.