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An investigation of the effect of retest practice on the relationship between speed and ability in attention, memory and working memory tasks

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Abstract

The research work reported in this paper addresses the question whether retest practice changes the speed-ability relationship. In three successive test sessions several cognitive tests of attention, memory and working memory were administered: Attention Switching Task, Continuous Attention Task, Memory Scanning Task, Letter Comparison Task, and Maintenance Summation Task. Retest practice led to substantial decreases of mean reaction time in the memory and working memory tasks while in attention tasks the effect was small or even insignificant. Intercepts, slopes and components representing sources with a constant, increasing and decreasing influence on responding were computed and correlated with ability. The results revealed that the correlation of the Letter Comparison task was large independently of retest practice. In contrast, for the Maintenance Summation Task the highest correlation was observed for the component representing the source with an increasing influence. Some retest practice seems to be necessary in order to establish the relationship of working memory and ability.

Key words: Retest practice; attention; working memory; reaction time; ability; trend analysis

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For a number of reasons the effect of retest practice on performance in completing cognitive tasks is a crucial issue of ability research. Change instead of constancy calls basic assumptions concerning cognitive processing into question. A number of studies have been conducted in order to investigate this issue. Most studies concentrated on this effect of retest practice on processing time. The gradual decline due to retest practice is nowadays considered as a well-establish fact. The initial decline is normally especially strong (Collie, Maruff, Darby, & McStephen, 2003). In subsequent trials the effect seems to become gradually smaller. In the long run the decline follows an asymptotic curve. A major cause of the improvement of performance seems to be the reduction of inconsistency of cognitive performance due to practice (Ram, Rabbitt, Stollery, & Nesselroade, 2005).

Changing performance as the result of retest practice is an annoyance for considerations concerning the speed-ability relationship. It calls the generality of results obtained in investigating the cognitive basis of ability into question. Substantial correlations between measures of speed pertaining to a number of perceptual and cognitive demands and ability led to the ascription of a prominent role to cognitive structures with respect to ability (Schweizer, 2005). However, in most cases there was only one testing session and the number of trials was usually quite limited. Consequently, although in many studies participants have to complete some practice trials before the test trials are started, the validity of the results can only be claimed for a restricted kind of low practice state.

There are attempts to provide an account of the effect of retest practice. A long time ago Schneider and Shiffrin (1977; Shiffrin & Schneider, 1977) characterized the low-practice state of information processing in two influential papers as controlled processing. Furthermore, they described this type of processing as ability-related whereas the other type: automatic processing, was not assumed to be ability-related. Recent papers associate controlled processing with a second-order concept denoted attentional control, executive attention or executive control (Engle & Kane, 2004; Heitz, Unsworth, & Engle, 2005, Moosbrugger, Goldhammer, & Schweizer, 2006; Schweizer, Moosbrugger, & Goldhammer, 2005). The transition from controlled to automatic processing, which was expected to occur because of so-called consistent mapping, was described as the result of practice. As a consequence, practice should lead to the disappearance of the speed-ability relationship whenever consistent mapping is involved.

Since the distinction of controlled and automatic processes does not enable the consideration of differences between cognitive tasks and cognitive abilities, Ackerman (1988) presented an alternative approach, which suggested different predictions with respect to different combinations of cognitive tasks and cognitive abilities. A major characteristic of this approach was the prediction of an increase of the correlation between performance in completing rather elementary tasks and psychomotor abilities due to practice. However, after a decade of research Ackerman (2000) revised this prediction because of the lack of change and suggested the construction of a taxonomy of elementary abilities in considering the effect of retest practice as major challenge for future research. However, meanwhile new ways of representing effects promise new insights (Ackerman, 2007).

Even in more complex cognitive tasks the effect of retest practice on the speed-ability relationship seems to be almost negligible. In a study by Stankov (1991) versions of the Tonal Memory and Hidden Figures Tests, which were presented as single and competing tests, were to be completed at eight occasions. The correlations between the performance scores and ability scores failed to reveal impressive trends. Actually, the correlations showed varia-

tions in both directions from the first to eighth occasions. Therefore, it is difficult to read a trend from the numbers. In another study Rabbitt and Goward (1994) selected the choice reaction time task for the assessment of elementary performance. The participants of the study had to complete ten blocks of 200 trials. The information provided by the authors for three IQ groups suggested that the relationships between the groups were retained although there was a general improvement of performance. From the available information we tentatively conclude that there is constancy of correlations. Neubauer and Freudenthaler (1994) also investigated the effect of retest practice on the relationship between performance in completing elementary cognitive tasks and ability. Their performance measure required the evaluations of sentence-picture combinations. After several hours of practice they found a small decrease of the correlation, which, however, was still well above the level of significance. Our own previous investigation (Rockstroh & Schweizer, 2004) included several types of elementary cognitive performance: memory scanning, letter comparison, continuous attention and attention switching. There were four test sessions. In the absence of correction for attenuation only the correlations of continuous attention and intelligence reached the level of significance. The sizes of the correlations suggested a correlational increase concerning performance in continuous attention.

Unfortunately, the majority of studies investigating the effect of practice on the speed relationship suffer from a methodological shortcoming. This shortcoming results from the use of correlations for investigating the effect of retest practice on the speed-ability relationship since usually one correlation is computed for each individual session, and these correlations are compared with each other subsequently. As a consequence, there is a multitude of results and a rather informal way of integrating these results. This is a situation comparable to the situation characterizing multitrait-multimethod investigations before the advent of appropriate confirmatory factor models (Kenny & Kashy, 1992; Marsh, 1989). Furthermore, it is difficult or even impossible to identify small increases or decreases in correlation since the detection of substantial increases or decreases by statistical tests requires rather large differences in correlation.

Therefore, we prefer the investigation of long-term effects and time-dependent trends as wholes. However, such investigations require the selection of a confirmatory approach. Such an approach enables the investigation of hypotheses, which refer to several measurement occasions or assessment sessions. In a recent study measurement occasions over a period of six minutes were investigated in considering various trends and selecting a latent variable approach (Goldhammer, Rauch, Schweizer, & Moosbrugger, 2009). A linear decrease in reaction time was observed. However, change showed no relationship with intelligence. In small numbers of sessions and limited sample size the component approach in combination with target-rotation (Schweizer, 2003) can be expected to provide more robust results than the latent variable approach. This way it is possible to decompose the variances of the variables and the components can be assumed to represent increasingly and decreasingly influential sources that give rise to trends. In the case that retest practice leads to an increase of the speed-ability relationship, the component representing the increasing trend should correlate with ability and in the other case the component representing the decreasing trend.

Objectives

Three aims characterized the present study. The first aim was the replication of some of the results of previous studies, which also considered some of the concepts of this study: memory and attention (Rockstroh & Schweizer, 2001, 2004). The second aim was the extension of the previous studies. Accordingly, another major concept of information processing was considered: working memory. The third aim was the systematic investigation of the relationships between trends respectively components representing change and ability by means of corresponding scores. This investigation was expected to enable interpretations, which referred to all the retest sessions.

Method

Participants

The sample included 63 participants. Among the participants there were 36 males and 27 females. The participants were between 20 and 35 years of age. In order to avoid errors due to unusual physiological states, the participants were asked to refrain from alcohol on the day before assessment and from caffeine and nicotine on the day of assessment.

Measures

Five measures for the assessment of performance in completing cognitive tasks were installed on a PC by means of the software package ERTS (Berisoft Cooperation Frankfurt, Germany). The visual stimuli were presented on the computer screen and the acoustic stimuli by means of a loudspeaker. The participants had to respond to stimulation by pressing the space bar if a response was necessary. The appearance of a target demanded a response whereas a non-target required abstaining from responding. In the case that a response was necessary, the time between stimulation and response was measured and stored on hard disk.

Memory Scanning Task. This task required retrieving information stored in short-term memory. It was constructed according to Sternberg's (1966, 1975) Memory Scanning Task. In each trial a series of four or five numbers were successively presented on the computer screen. The presentation time was 300 ms and the interstimulus interval 700 ms. After a break of 2 s a probe stimulus appeared, and the participant had to decide as fast as possible whether it was a target or a non-target. It was a target if it corresponded to one of the initially presented numbers. There were 12 response trials and 6 non-response trials.

Letter Comparison Task. The Letter Comparison Task of this study was constructed according to Posner and Mitchell's (1976) Letter Comparison Task. This task required the comparison of letters with respect to categorical identity. There were two categories: the categories of vowels and consonants. Completing this task required access to information stored in long-term memory. Sets of two randomly selected letters were presented on the computer screen for a maximum of 2.5 s. The participant had to decide as fast as possible whether the letters were taken from the same category or from different categories. In the case of the same category the space bar had to be pressed as fast as possible. A warning

signal initiated each trial. The participant had to complete 25 trials, of which 20 were target trials.

Maintenance Summation Task. The Maintenance Summation Task of this study was constructed according to a task presented in a paper by Kyllonen and Christal (1990) as working memory task. This task required the maintenance of information, the processing of the maintained information and the comparison of the result of processing with the target. In each trial two two-digit numbers appeared on the computer screen. These numbers had to be retained for processing after the removal from the screen. The next step was initiated by the appearance of either "+1" or "+2" (incremental number) on the screen. The first stimulus required the increase of each one of the two-digit numbers maintained in memory by 1 and the second stimulus by 2. The results of the arithmetic operations had to be compared with another set of two two-digit numbers, which served as targets and appeared at the same time as the incremental number. In the case of a perfect match the space bar had to be pressed. There were 27 trials of which 20 trials required the pressing of the space bar.

Continuous Attention Task. The Continuous Attention Task required the shift of attention from one stimulus to the next stimulus, which appeared on the computer screen, and at the same time from stimulus to stimulus, which were maintained in memory, for a prolonged period of time. This task was constructed according to a description originally provided by Talland (1966) and became known as Rapid Visual Information Processing Task (e.g., Wesnes & Warburton, 1984). For 2 min one-digit numbers were successively presented at the same spot on the computer screen. Each presentation lasted 150 ms, and two successive presentations were separated by an interstimulus interval of 850 ms. The participant had to respond to three successive presentations of the same number by pressing the space bar as fast as possible. The sequence included 16 targets.

Attention Switching Task. This task served the assessment of the speed of shifting the attentional focus between different informational channels. The original description of this task was provided by Sutton, Hakerem, Zubin and Portnoy (1961). It required shifting the attentional focus between the acoustic and visual channels. A large cross was presented as visual stimulus and a tone of 1000 Hz as acoustic stimulus. The stimuli appeared according to a pseudo-random sequence. The presentation time was 150 ms and the interstimulus interval ranged from 1500 to 2500 ms. The participant had to press the space bar after the appearance of each stimulus. There were 30 trials.

Psychometric measure

The LPS scale 4 (Horn, 1983) served as psychometric measure. This scale required the participants to complete series of letters and/or numbers. It was selected because it was found to show very high loading on the general ability factor in previous studies (Schweizer, 1993, 1994). The Alpha consistency of this scale was .80.

Procedure

There were three test sessions which were separated by breaks lasting for two hours. The series of stimuli were not held constant from session to session. Instead, each test session

received its own series of stimuli, which were composed to be equally demanding. The five measures of elementary cognitive performance were presented in the following sequence: Memory Scanning Task, Letter Comparison Task, Continuous Attention Task, Attention Switching Task, Maintenance Summation Task. Each series of test trials was preceded by a few practice trials in order to assure familiarity with the task.

Data analysis

The median values of the individual measurements served as reaction times. Since wrong responses indicated inappropriateness in processing, only the measurements of correct responses were included in the computations. MANOVA served for the investigation of the practice effect on reaction times. Since the investigation of the speed-ability relationship was in the focus of this investigation, several approaches were considered in analysing the data. Firstly, an intercept and a slope parameter were computed for each participant and each task. This approach assumed that change could be described sufficiently well by a linear function at the individual level. Since there were only three test sessions, this assumption could be accepted as reasonable. The intercept and slope parameters were expected to enable the investigation of the relationship between individual change and ability in a more general way than simply considering the differences between correlations. Secondly, scores representing latent trends were determined by means of principal component analysis. Principle component analysis was selected because it is rather robust and can be expected to do well in moderate numbers of participants. Three scores were generated. The first score was the result of a general component model. The corresponding component represented a source of responding that could be assumed to exert a constant influence. The second and third scores were obtained by means of a two-component model. The extraction was restricted to two components, which were subsequently rotated by means of Promax with a weight specification of 6. Promax rotation was applied as target rotation procedure. Typically one rotated component showed a very high loading ($\lambda>.80$) of the first session and a moderate loading ($\lambda<.40$) of the third session whereas the other rotated component showed a moderate loading ($\lambda<.40$) of the first session and a very high loading ($\lambda>.80$) of the third session. The sizes of the loadings of the second session were in both cases between the sizes of the other loadings. As a consequence, one of the components could be taken to represent a source that was especially influential in the first test session and ceased to be influential afterwards. In contrast, the other component was assumed to represent a source that was increasingly influential.

Results

The effects of retest practice on means

At first, the session means were determined for each reaction time tasks. The results are presented in Table 1.

Table 1:
Mean reaction time for the test sessions and results of repeated MANOVA

Reaction time task	Session 1	Session 2	Session 3	F	df	p
Memory Scanning	307	291	290	13.47	2,124	.00
Letter Comparison	663	617	608	6.49	2,124	.00
Maintenance Summation	1358	1275	1238	5.26	2,124	.00
Continuous Attention	364	352	343	3.29	2,124	.04
Attention Switching	580	568	572	0.61	2,124	n.s.

The differences between the mean reaction times were remarkable. They probably reflected different degrees of complexity in information processing. Memory scanning and continuous attention led to arithmetic means, which surmounted the simple reaction time of corresponding samples by a small amount only. Letter comparison and attention switching showed a considerable increase, which indicated the occurrence of additional processes. The largest reaction times were due to the maintenance summation demand. These demands were the most complex ones.

The comparison of the means revealed a monotonic decrease from the first to third sessions in four of the five tasks. There was only one exception. A small increase from the second to third sessions was observed for attention switching. In each case the step from the first to second sessions included the largest change in reaction time. The differences between the means were investigated by means of repeated MANOVA. The results of this investigation are also provided in Table 1. Highly significant differences were indicated for memory scanning, letter comparison and working memory. The differences observed for continuous attention only reached the 4-percent level of significance, and an insignificant result was found for attention switching. In sum, the means of the memory tasks including the working memory task showed substantial effects due to retest practice whereas the effects concerning attention tasks were small or even insignificant.

The effects of retest practice on correlations

In the next step sessions were compared with respect to the correlations with intelligence. Figure 1 includes graphical representations of the correlations that highlight the trends.

Since negative correlations were expected, the results suggesting a substantial speed-ability relationship can be found in the lower part of this Figure. Only memory scanning and the maintenance summation demand led to substantial correlations. The lines connecting the correlations were expected to make trends especially obvious. The correlations concerning letter comparison suggested a weak decrease in absolute size. In contrast, for the working memory task a strong increasing trend in absolute size was observed.

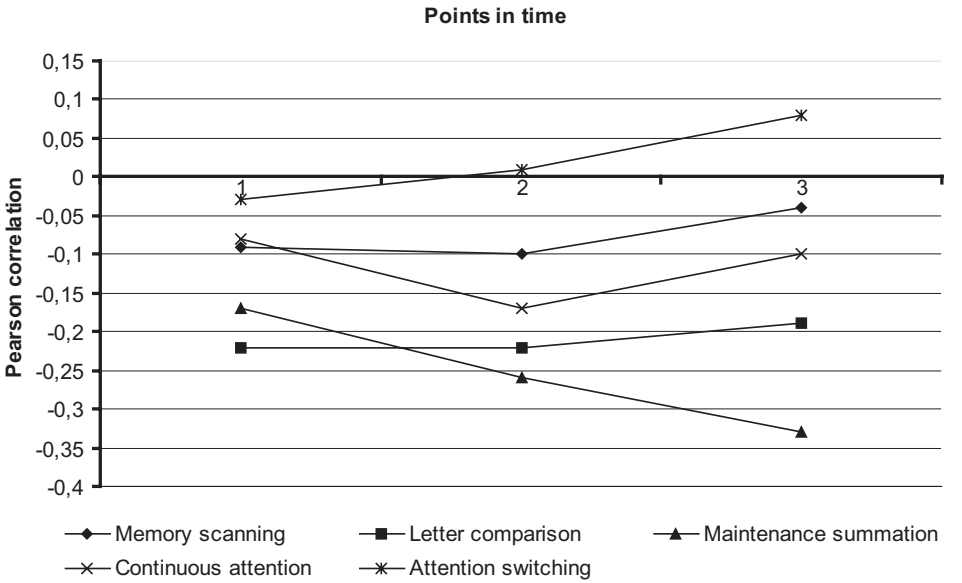

Figure 1:
Graphical representation of the trends of the speed-ability relationship in considering the three points in time for the five reaction time tasks

The effects of retest practice on the correlations between trend scores and intelligence

Results according to the regression model. In the next step the intercept and slope parameters were correlated with intelligence. The results are reported in the first and second columns of numbers of Table 2.

All the correlations of intercept parameters were negative whereas some of the correlations of slope parameters were positive and some negative. However, no one of these correlations reached the level of significance. Of special interest were the correlations of letter comparison and of the maintenance summation demand. It was interesting to observe that in letter comparison the intercept parameter led to the higher correlation and in maintenance summation the slope parameter.

Results according to the component model. Three component scores were computed by means of Principal Component Analysis with target rotation (see section on data analysis). Subsequently, the component scores were correlated with intelligence. The results of this investigation are included in the third to fifth columns of Table 2. The third column gives the results for the constant component score. The correlations observed for letter comparison and the maintenance summation demand reached the level of significance. These correlations indicated a relationship with intelligence, which was independent of retest practice. The fourth column provides the results for the component, which was assumed to have an in-

Table 2:
Pearson correlations between the general intelligence (LPS-4) and slope and intercept of individual reaction time and also three component scores representing constancy, increasing and decreasing effects

Reaction time task	Intercept	Slope	Constancy	Increasing effect	Decreasing effect
Memory Scanning	-0.09	0.05	-.10	-.06	-.11
Letter Comparison	-0.19	0.06	-.25*	-.22*	-.23*
Maintenance Summation	-0.08	-0.15	-.29*	-.32**	-.18
Continuous Attention	-0.08	-0.01	-.13	-.14	-.10
Attention Switching	-0.07	0.15	.02	.07	-.03

Note: * $p<.05$, ** $p<.01$, one-sided.

creasing influence on performance. Again, the correlations observed for letter comparison and the maintenance summation demand reached the level of significance. The comparison of these correlations with the corresponding correlations of the third column made differences obvious: in letter comparison the absolute size of the correlation of the constant trend scores surmounted the absolute size of the correlation associated with the increasing trend. Apparently, the component associated with the increasing trend did not accumulate variance that showed a special relationship with intelligence. In contrast, in the maintenance summation demand the component suggesting an increasing influence of a source reached the largest size. It remains the fifth column, which included the correlations of the component associated with a decreasing influence on responding. Only the correlation of letter comparison and intelligence reached the level of significance. The size of this correlation was also smaller than the size of the correlation for the constant component. Consequently, this component could not be assumed to accumulate variance that showed a special relationship with intelligence.

These correlations told us different messages. In letter comparison the message was that there was a source that constantly contributed to the speed-ability relationship since the sizes of the correlations of the increasing and decreasing components almost exactly corresponded and were lower that the correlation of the component associated with the constant trend. Apparently, retest practice did not change the correlation of performance in comparing letters and intelligence. In contrast, the results suggested an increase in correlation for the task representing working memory. There were two indications: the correlation suggesting an increasing influence on performance surmounted the correlation suggesting a constant influence, and the correlation concerning the increasing influence reached the level of significance whereas the correlation suggesting a decreasing influence did not.

Discussion

The main issue of this paper is the trend of the correlation between intelligence and basic cognitive efficiency resulting from retest practice. This issue is of enormous importance because of a number of reasons: Firstly, there are the consequences for the assessment of

narrow and broad abilities by means of cognitive tasks which represent basic abilities and skills. If there is an increasing or decreasing trend of correlation, it arises the question how much practice is acceptable respectively appropriate in the assessment of the corresponding concept, and for future research the necessity may arise to care for the comparability of the practice levels of testees. Secondly, there is the question whether retest practice leads to a modification of information processing in a similar way as the modification characterizing the transition from processing of novices to processing of experts. This question is closely related to the question whether it is novelty, which causes intelligence to contribute to information processing (Sternberg, 1985). Thirdly, the results concerning this issue are important with respect to the concept of intelligence since basic cognitive efficiency is closely associated with the biological basis of intelligence (see Schweizer, 2005). A changing relationship between basic cognitive efficiency and intelligence due to retest practice suggests that the basis of intelligence is not a static structure of sources. Instead, such a change may be interpreted as the indication of cognition as a dynamic system that shows a specific kind of adaptation to enduring demands.

The investigation of the practice effect on the correlation between basic cognitive efficiency and intelligence yielded two interesting results. The first one, which is the most interesting result, suggests an increase of the correlation between working memory and intelligence due to retest practice. It is tentatively suggested that in the beginning the working memory task is too demanding for the participants, probably because of the high degree of complexity (Stankov, 2000). There is an initial inability to follow the instructions properly so that sources of error dominate performance. The working memory task seems to be so demanding that the initial mapping of the instructions into a sequence of cognitive operations is insufficient and causes error. As a consequence, the correlation is low in the beginning. The subsequent increase in correlation is presumably due to the gradual elimination of sources of error. The establishment of associations between cognitive operations and automation due to retest practice reduces the probability of errors and, as a consequence, shortens the reaction time. Secondly, for the task requiring letter comparison the result suggests constancy of correlation although the inspection of the correlations conveys the impression that there is a decrease. Apparently, in this case the reduction of the mean reaction time is not accompanied with a change of correlation. The constancy of correlation suggests that the reduction in reaction time is due to the reduction of the error component and at the same time of the true component. The change due to retest practice seems to apply to all types of cognitive processes equally. The results concerning other tasks need not to be discussed in detail since the level of correlation was low. These results do not give reason for assuming trends deviating from constancy.

Only two of the five tasks led to substantial correlations with intelligence. The substantial correlations were restricted to memory and working memory. Surprisingly, the attention tasks did not lead to substantial results. In a previous study including only one session substantial results were observed for all the investigated types of attention (Schweizer, Moosbrugger, & Goldhammer, 2005). The failure of the present study is probably due to sample size. Because of the large sample size even small correlations led to substantial results at the latent level in the previous study. Therefore, failures to reach the level of significance within this study should not be considered as definitive failures since time and energy was invested in retest practice in this study.

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