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The relation of speeded and unspeeded reasoning with mental speed

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Abstract

Time constraints are commonly applied in the measurement of reasoning ability. We argue that time constraints introduce a spurious mental speed contribution to task performance. As a result, speeded measures of reasoning are conceived as a compound of two functions, namely working memory capacity and mental speed ability. We tested 277 participants with 12 reasoning tasks (six time constrained), and 9 mental speed tasks. Additionally, 90 participants worked on both batteries under timed conditions. The correlations of observed scores as well as factors in a latent variable model show the expected pattern: Mental speed correlates higher with speeded than with unspeeded reasoning measures. Two speeded reasoning tests correlate higher than a speeded and an unspeeded test. The results also indicate that the variance of a speeded reasoning factor can be explained completely by a linear function of unspeeded reasoning and mental speed. It is concluded that the use of speeded reasoning tests is likely to lead to overestimates of the relation between mental speed and reasoning ability.

Keywords: Speeded and unspeeded testing; Reasoning; Mental speed; Processing speed; General intelligence

1. Introduction

Most reasoning tests are administered under some type of time constraints. There seem to be at least two main reasons why time constraints are used in the measurement of reasoning

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ability. The first is that test performance is conceptualized as output per time unit. In this case, both the time required and accuracy of cognitive processes are of major interest. The second reason is that some time limit is required for pragmatic purposes in group-testing situations in order to proceed efficiently through test administration.

Time constraints supposedly introduce speededness into a test when less than 90% of a sample completes all items (Nunnally & Bernstein, 1994). Implicit in definitions of speededness is that not (nearly) all items are answered by (nearly) all participants, or if participants perceive time pressure when working on the test. Frequently, it is assumed that the introduction of time constraints in the measurement of ability has no influence on the instrument's validity.

Several problems are associated with the widespread use of speeded tests for the measurement of reasoning ability. One is that the degree of speededness of a test cannot easily be expressed as items per time unit because item difficulty is an important determinant of required time (Thurstone, 1937). Another problem is that the effect of speededness on the psychometric properties of a test is usually unknown. In psychometrics, three groups of approaches have been developed to express the speededness of a test. The first approach is to describe speededness as the number of items that participants did not work on, or as the difference between the numbers of missed items under speeded and unspeeded conditions (e.g., Lienert & Ebel, 1960). These and similar indices are used primarily to communicate descriptive test properties. A second approach is to provide indices that are based on the relative amount of variance attributed to speeded versus unspeeded test administration in total test scores or on the correlation between speeded and unspeeded total test scores (Cronbach & Warrington, 1951; Gulliksen, 1950; Helmstaedter & Ortmeyer, 1953; Paterson & Tinker, 1930). More succinctly, these approaches can be described as based on (co)variability of total test scores. The third approach relies on probabilistic models of test performance giving special attention to omitted items and the time course of performance on items (Furneaux, 1960; Iseler, 1970; Nährer, 1986; White, 1982). These models particularly aim at an explanation of the response behavior in terms of latent variables. All of the above-mentioned psychometric methods center around the desire to find appropriate ways to describe the speededness of a test and the behavior participants show in tests, for example, to gain adequate reliability estimates or person parameters.

However, the above approaches only indirectly and vaguely address the possibility that the speededness of a test might change its validity to a substantial degree. Apart from some psychometric efforts on the degree of speededness of tests, little research has been done comparing speeded and unspeeded conditions and their respective correlations with mental speed. This is surprising given the possible implications for tests of theories of intelligence structure (e.g., Carroll, 1993, p. 460). There are at least two problems with speeded measures of intelligence factors. One is that the correlations between factors could be overestimates due to similar administration conditions. The other is that the interpretation of factors might be biased to the degree that performance does not depend on the respective construct, but rather on the speed with which some observed behavior is produced.

The relationship between mental speed and reasoning ability is at the heart of the debate about the importance of *g* as an overarching construct for measures in the domain of intelligence. The positive relationship between classes of indicators of both constructs is taken as evidence supporting the view that the speed of information processing is basic to human intelligence (Eysenck, 1987; Jensen, 1982; 1998; Vernon, Nador, & Kantor, 1985). In this view, it is maintained that the more quickly the information in working memory can be processed, the less likely it would be that the restricted capacity of working memory will be reached, or that earlier encoded information will be decayed or inaccessible. In such a model, performance on tasks that mainly require working memory capacity benefits from higher mental speed.

In contrast to this view, the magnitude of the relationship between mental speed and reasoning ability could be regarded as a function of task complexity (Larson, Merritt, & Williams, 1988; Marshalek, Lohman, & Snow, 1983). Taking task complexity into account, a general and simple rule can be induced: The more complex a mental speed task, the higher its correlation with reasoning will be (Hunt, 1980; Stankov & Roberts, 1997). As Marshalek et al. (1983) have shown, intelligence tasks can be organized along a complexity continuum in a radex structure where reasoning is at one endpoint and mental speed at the other. The proposed complexity dimension for intelligence tasks can be understood as a function of two abilities, working memory capacity and mental speed. The relative contribution to task performance by working memory capacity and mental speed varies depending on the location of an intelligence test task on this continuum. The complexity dimension has high working memory capacity and low mental speed demands at the one end and high mental speed and low working memory capacity demands at the other. All other things being equal, the closer two tasks are located on that dimension, the higher their correlation. We will label this theory the "two functions view."

Adopting these theoretical assumptions, mental speed should be a potent indicator of reasoning (as well as general intelligence) under two conditions; first, when complex as opposed to simple mental speed tasks are used; and second, when speeded as opposed to unspeeded reasoning tasks are used. Under the first condition, when mental speed tasks are rather complex they can be assumed to include substantial variance due to individual differences in working memory capacity. Research investigating reasoning ability suggests a strong or perfect relation with working memory capacity (Engle, Tuholski, Laughlin, & Conway, 1999; Kyllonen, 1996; Kyllonen & Christal, 1990; Süß, Oberauer, Wittmann, Wilhelm, & Schulze, in press). In this paper then, we will treat reasoning ability to be equivalent to working memory capacity. Consequently, more complex mental speed tasks should correlate more highly with reasoning than simple mental speed tasks. Hence, any relation between reasoning and information processing speed as measured by complex mental speed tasks will be an overestimation of the true size of the relationship between both constructs. Under the second condition, reasoning tasks are administrated under speeded conditions. The time pressure on performance selectively favors persons with high mental speed because the greater the mental speed the greater the number of items worked on (Carroll, 1981; Sternberg, 1984). At least one of these two conditions is met in most of the studies reporting a strong relationship between reasoning ability and mental speed (e.g., Neubauer & Bucik, 1996). To yield an unbiased estimate of the relationship between the speed of information processing and reasoning, simple mental speed measures and unspeeded reasoning tasks should be used.

Two procedures are suitable to explore the hypothesis of a complexity dimension of intelligence tasks. The first procedure is to manipulate the complexity of tasks that measure information-processing speed. There is abundant evidence that the correlation between mental speed and reasoning is a function of complexity (Roberts & Stankov, 1999). However, a great variety of complexity manipulations can be used (e.g., increase of memory load, secondary task, difficulty of decision to be performed, and many more) and not all of these manipulations show the same effect. The second procedure is to reduce or eliminate time constraints on reasoning tasks. This path of research has rarely been employed when investigating the relationship between mental speed and reasoning.

Prior research manipulating time constraints seems to support the view of a speed-dependent working memory. In two studies, Vernon et al. (1985), as well as Vernon and Kantor (1986), investigated the relationship of processing speed with speeded and unspeeded reasoning. The first of these studies was criticized by Sternberg (1986) (but see also Odoroff, 1935), as well as by Vernon and Kantor because speeded and unspeeded reasoning ability were not experimentally independent. In the second study, Vernon and Kantor do, indeed, show a slight but nonsignificant increase in correlations for the participants working on unspeeded tasks. However, four of the six tasks used to measure mental speed by Vernon et al. and Vernon and Kantor seem to involve substantial amounts of simultaneous storage and processing. Performance on these tasks should consequently reflect individual differences in working memory capacity to a substantial degree. For example, the sentence verification test (TRFAL) involves deductive reasoning. Baddeley (1968) proposed a highly similar task as a short reasoning test (see also Carter, Kennedy, & Bittner 1981), but Vernon et al. classified it as a speed of processing test.

If working memory capacity cannot be reduced to mental speed, the classification of tasks that tap working memory capacity as indicators for mental speed is not acceptable. In current conceptions of working memory (e.g., Miyake & Shah, 1999; Oberauer, Süß, Schulze, Wilhelm, & Wittmann, 2000), the speed of elementary cognitive processes is not considered a major limiting factor on working memory performance (but see Salthouse, 1996). There is no sufficient theoretical rationale to reduce working memory capacity to mental speed (Stankov & Roberts, 1997). The results of Vernon and Kantor are therefore inconclusive.

Assuming a speed-dependent working memory, the more difficult a reasoning item is, the heavier the burden on working memory. The heavier the burden on working memory, the more beneficial is high mental speed. Hence, an increase in the correlation between reasoning ability and mental speed would be predicted if the time constraints on a reasoning test are relaxed. In other words, reasoning ability measured under untimed conditions contains more mental speed variance than reasoning ability measured under timed conditions.

The speed-dependent working memory theory itself does not allow formulation of a precise hypothesis with respect to the relationship between unspeeded and speeded reasoning ability compared to the correlation of two speeded measures of reasoning ability. Vernon and Kantor (1986) predict an increase in the correlation of reasoning with mental speed from speeded to unspeeded conditions. Vernon et al. (1985) hypothesize that the more difficult items, towards the end of a test, are more frequently reached in unspeeded than in speeded reasoning tests. Solving the more difficult items places increasingly greater demands on subjects' working memory and following Vernon, on mental speed. Because speeded as well as unspeeded reasoning performance should depend on information processing speed, and because subjects work on more items in unspeeded conditions, there should be more systematic variance in unspeeded reasoning ability. Following this line of reasoning, disattenuation leads to an increase in the correlation between speeded and unspeeded reasoning measures as compared to two speeded reasoning measures. This assumption should hold on a manifest level. On a latent level, disattenuation would have no effect on the size of relations.

Different predictions follow from the two functions view. When manipulating the time constraints on measures of reasoning ability, the difficulty of the tasks is not actually changed. Increasing available testing time just ensures that a higher proportion of participants work on a higher proportion of items. Ideally, every participant would work on every item, though not necessarily producing a response. Strict time constraints will affect participants differently. Participants with high mental speed will finish items faster and, as a result, they will work on more items within the time limits. In time constrained conditions, the subjects that rapidly go through a test have an essential advantage over slow participants—other things being equal, they will have more trials to solve the problems. The number of wrong answers is usually not explicitly part of the score (but see Traub & Hambleton, 1972), and fast participants will thus get better results. As a consequence, the correlation between mental speed and reasoning will be elevated. Introducing effective time constraints for measures of reasoning ability will increase the correlation with mental speed. Time constraints are effective when a substantial proportion of participants is unable to attempt a solution on a substantial proportion of the items. Beyond a certain level, further increases in time constraints will only reduce the amount of systematic variance. The contributions of abilities that are beneficial for test performance in speeded and unspeeded reasoning tests are unequal. In unspeeded reasoning tests, working memory capacity will be the most prominent limiting factor. In speeded reasoning tests, mental speed is a second limiting factor. Following this line of reasoning, we predict that speeded reasoning tests will correlate higher with mental speed than unspeeded reasoning tests. A second prediction is that the correlation of unspeeded reasoning ability with speeded reasoning ability is lower than the correlation between two speeded measures of reasoning ability. Lastly, we predict that the variance of speeded reasoning ability can be completely explained by measures of unspeeded reasoning ability and mental speed, that is, speeded reasoning ability can be conceived as a linear function of unspeeded reasoning ability and mental speed.

2. Method

2.1. Participants and procedure

Participants were 367 high school students (149 male, 216 female; two participants did not indicate their sex), who received feedback of their results as reward for participation in the study. The mean age for all participants was 15.8 years (S.D. = 1.7), ranging from 13 to 22 years.

A total of 23 classes were assigned to one of six groups in order to achieve nearly equal mean ages in the groups. Descriptive statistics for the six groups are presented in Table 1.

Two reasoning tests were administered in varying order across the six groups. To control for sequence effects Groups 1 and 3 worked on Test 1 first and on Test 2 subsequently (see Table 1), whereas Groups 2 and 4 took the tests in reverse order. Additionally, the order of timed and untimed administration of the tests was manipulated across the four groups. To control for effects resulting from sequence of these conditions, Groups 2 and 3 worked on reasoning tests under the untimed condition first and the timed condition thereafter. The reasoning tests were presented in reverse order of conditions for Groups 1 and 4. After working for about 75 min on the 12 reasoning tasks, participants in Groups 1–4 worked on all nine mental speed tasks, which took about 15 min.

To yield an estimate of the correlation of two speeded reasoning tests, two further groups (Groups 5 and 6) worked on both tests under timed conditions in varying order. Additionally, although not of concern in this paper, a newly developed propositional reasoning test was administered to Groups 5 and 6 after they completed the reasoning tests.

Because tests were administrated in groups, some time limits were necessary in untimed conditions. Time limits were explored in a pilot study with eight subjects from the lower bound of the age and ability distribution of the final sample. Results indicated that all subjects of the pilot study were able to work on all the items in both reasoning tests if time limits from timed administration of the reasoning tests were multiplied by 2.5. Consequently, time limits for untimed conditions were set to 2.5 times the original administration time under timed condition for every task in both tests. The extension of time limits is in the same range as in prior research (Peak & Boring, 1926; Traub & Hambleton, 1972; Vernon & Kantor, 1986). Furthermore, participants in the four groups were asked whether they needed more time to work on the tasks under untimed conditions. Subsequent tasks began when all participants were finished.

Table 1
Mean ages and frequencies of male and female participants in the six groups

Group	*n*	Mean age (SD)[a]	Sex[b]		Test under timed versus untimed condition	
			Male	Female	Timed	Untimed
1	83	15.6 (2.1)	31	52	Test 1[c]	Test 2
2	69	15.7 (1.5)	22	46	Test 1	Test 2[c]
3	64	15.2 (1.5)	25	39	Test 2	Test 1[c]
4	61	16.2 (1.7)	27	33	Test 2[c]	Test 1
5	47	16.4 (1.1)	25	22	Test 1[c] Test 2	–
6	43	15.8 (2.0)	19	24	Test 1 Test 2[c]	–

[a] Three participants did not report their age in Groups 1, 3, and 4, respectively.

[b] Two participants did not report their sex in Groups 2 and 4, respectively.

[c] Tests were given first.

2.2. Measuring instruments

The items used in the present study are taken from the Berlin Model of Intelligence Structure (BIS)-4 test, which is the most recent test for the BIS (Jäger, Süß, & Beauducel, 1997). The BIS is a bimodal and hierarchical model of intelligence structure that distinguishes between a content and an operation facet (Jäger, 1984; for an English description see Carroll, 1993). On the content facet of the BIS, the materials with which intellectual operations are carried out are important. Accordingly, subtests are classified as *figural*, *numerical*, or *verbal*. On the operation facet, *processing capacity* (reasoning), *processing speed* (mental speed), *memory*, and *creativity* are distinguished. Here, the type of intellectual operation that the subtests demand is of importance. Because memory and creativity were not of concern in the present study, subtests for the measurement of these abilities were omitted from test materials. Processing capacity in the BIS is described as ‘‘capacity for processing power/formal logical thinking and judgment ability’’ (Carroll, 1993, p. 64). Empirical research (Jäger & Tesch-Römer, 1988) has confirmed the interpretation of processing capacity as reasoning.'[2] Because of the conceptual closeness of processing speed and mental speed, these are also equated. The results reported by Neubauer and Bucik (1996) support this equation. They report a bivariate correlation between factor scores of a general factor from 24 mental speed tasks and processing speed in the BIS-4 test of $r = .75$, the highest correlation of the general mental speed factor with any of the operational abilities of the BIS. It might be added here that Neubauer and Bucik (1996) refrain from equating mental speed and processing speed because of substantial correlations of mental speed with other abilities in the BIS. In our view, these correlations might partly be attributed to administration of the test under time-restricted conditions.

Although we do equate processing speed as measured by the BIS-4 test and mental speed, three potential differences could attenuate the correlations between various forms of mental speed tests. First, whereas in some measures, speed is expressed as number correct per time unit, in other measures, speed is expressed as time units per correct response. Second, some speed measures are administrated as paper-and-pencil tests, whereas other speed tests are computer administered (Mead & Drasgow, 1993). Third, performance on mental speed tasks can be measured as response latency after onset of a stimulus or it can be measured including latency on intertrial intervals. As a result, different artifacts, such as typical work speed or individual differences in phasic alertness, can have attenuating influences on the correlations between measurements. Apart from these three aspects, we see no major difference between various forms of mental speed tasks. Manipulating tasks along these dimensions is unlikely to alter the pattern of results reported in this study.

Twelve reasoning subtests were used in the present study. Six reasoning subtests from the BIS-4 test were selected for each of the two reasoning tests used in the present study. One set corresponds to the short form of the reasoning scale in the BIS-4 test. The six subtests of the

[2] Carroll (1993, p.64) points out the similarity of processing capacity with g_f in the Cattell–Horn model of intelligence.

Table 2
Subtests of the reasoning and mental speed tests

Subtest	Content classification	Description
Reasoning Test 1		
Sequences of numbers	Numerical	Sequences of numbers following certain rules have to be completed.
Figure analogies	Figural	One of five figures has to be chosen to complete a figural analogy of the form A:B::C:?.
Verbal analogies	Verbal	One of five alternatives has to be chosen to complete a verbal analogy of the type A:B::C:?.
Estimation	Numerical	Complex mathematical problems that can either be estimated or solved through simple mathematical operations.
Charkow	Figural	A sequence of line drawings, which are composed according to certain rules, has to be completed with the two following figures.
Fact–opinion	Verbal	It has to be found out whether given assertions are expressions of facts or opinions.
Reasoning Test 2		
Numerical reasoning	Numerical	Ordinary arithmetic problems have to be solved. All items are framed as everyday problems.
Unfolding	Figural	An unfolded drawing of a geometrical body is given. The body which could be made out of the model has to be selected out of five given bodies, which are different in form and perspective.
Comparison of conclusions	Verbal	Statements are given. For the following conclusions, it has to be evaluated whether the conclusions are logically valid or not.
Sequences of letters	Numerical	Sequences of letters following certain rules have to be completed with two letters.
Choice of figures	Figural	One of five geometrical figures is cut into several parts. Subjects have to indicate which one could be made out of the parts.
Vocabulary	Verbal	One out of four words in a line differs in its meaning from the other words. This one has to be crossed out.
Mental speed test		
x Greater	Numerical	All numbers in a list that are x-greater than the previous number have to be crossed out (x being a given number).
Old English	Figural	In rows of letters, all letters of a certain font have to be crossed out.
Part–whole	Verbal	In word lists two words related as part and whole (e.g. house, roof) sometimes follow each other. In cases where the whole stands directly above the part, it has to be marked.
Seven divisible	Numerical	In rows of two digit numbers, all numbers that can be divided by seven have to be crossed out.
Crossing out letters	Figural	A certain letter has to be crossed out in sequences of letters.
Incomplete words	Verbal	Some letters in given words are missing. These words have to be completed.
Arithmetic operator	Numerical	In easy equations, there are empty boxes instead of plus and minus signs. The correct signs have to be filled in.

Table 2 (*continued*)

Subtest	Content classification	Description
Digit–symbol	Figural	Pairs of numbers and symbols are given. In the fields below, the corresponding symbols have to be found for each number in a list of numbers.
Classification of words	Verbal	In columns of words, all plants have to be crossed out.

other reasoning test were selected from the remaining nine reasoning subtests of the BIS-4 test to match the short form in administration time and part–whole correlations of the subtests reported in the manual (see Jäger et al., 1997). Additionally, all nine mental speed subtests from the BIS-4 test were included in the study.

In the reasoning tests, there were two, and in the mental speed tests, there were three subtests of figural, verbal, and numerical content, respectively. Table 2 provides an overview and descriptions of the subtests of the three tests used in this study.

The scoring procedure for the tests was as follows. First, the number of correctly solved items for each of the subtests was recorded. Second, these scores were standardized across Groups 1–4, regardless of condition. Third, means of these standardized scores were computed for both reasoning tests under timed and untimed conditions, and the mental speed test, respectively. For every participant, this procedure resulted in two scores for the reasoning tests and one for the mental speed test, all of which had an overall mean of zero across the four groups. These scores were used in subsequent analyses of means and correlations. Additionally, following the procedure proposed by Jäger (1982),[3] subtest parcels were built for both *conditions*, ignoring test form and sequence of test, and the mental speed test as input for structural equation modeling. Only two reasoning parcels were built separately for each condition, regardless of test form, because only six subtests were available for parceling the reasoning tests. The parcels consisted of one subtest from each content aspect. Parcels, heterogeneous with respect to content aspects, were built to suppress unwanted content variance when the focus is on operations (Cattell & Tsujioka, 1964; Wittmann, 1988). Three mental speed parcels, also heterogeneous with respect to content aspects, were built from the nine subtests.

3. Results

3.1. Manipulation check

Time limits under timed condition for the subtests of the BIS usually lead to missing values due to items not reached. Therefore, performance on the subtests in terms of number of

[3] See also Wittmann (1988) for a detailed description and justification of this procedure.

Table 3
Group means and standard deviations of timed and untimed conditions

Group	*n*	Timed condition		Untimed condition	
		M	SD	*M*	SD
1	83	− 0.51	0.55	0.32	0.52
2	69	− 0.25	0.52	0.39	0.54
3	64	− 0.41	0.52	0.32	0.59
4	61	− 0.44	0.44	0.65	0.54

correctly solved items was expected to improve considerably when time limits were removed. Accordingly, means of aggregated reasoning subtests in timed and untimed conditions were compared. Table 3 reports the means and standard deviations for Groups 1 through 4.

All mean differences between the timed and untimed conditions are in concordance with our expectations. However, it is not clear whether these differences might in part be attributable to differences in sequence of conditions. As a consequence, these differences were tested in a two-way repeated-measures ANOVA, with condition (timed vs. untimed) as a within-subjects factor, and sequence of conditions (first timed vs. first untimed) as a between-subjects factor. As might be expected, the within-subjects factor of condition was significant and large [$F(1,275)=947.88$, $P<.01$, $\eta^2=0.78$], although there was also a significant interaction between condition and sequence of conditions [$F(1,275)=23.12$, $P<.01$, $\eta^2=0.08$]. A test of sequence of conditions as between-subjects factor revealed no main effect [$F(1,275)=0.17$, $P=.68$, $\eta^2=0$].

Post hoc analyses showed that the significant interaction effect was attributable to the elevated mean of Group 4 under untimed condition. A planned contrast of Group 4 versus Groups 1 through 3 did not show significant differences under timed condition [$t(273)=0.67$, $P=.25$]. Hence, the elevated mean of Group 4 under timed condition is not attributable to a higher overall ability level. In sum, the prolongation of administration time did, indeed, raise the performance level of all groups and the sequence of tests showed no overall effect, though one group did benefit slightly more than others from the relaxation of time constraints.

3.2. Correlational analyses

As a first step to test the hypotheses concerning the relationship between speeded and unspeeded reasoning and mental speed, correlations between ability estimates based on the total sample were computed (see Table 4). Though there was no main effect on the means

Table 4
Correlations of reasoning and mental speed tests

	Mental speed	Speeded reasoning	Unspeeded reasoning
Mental speed	.82	.49	.34
Speeded reasoning		.69	.64
Unspeeded reasoning			.69

Above the main diagonal correlations, on the main diagonal Cronbach's alpha computed from parcels.

for the sequence of the tests, differences between groups might have influenced the covariance structure to be used in the following analyses. We therefore tested the variance–covariance matrices of Groups 1–4 for equality, using a multiple group setup with AMOS 4.01 (Arbuckle, 1999). The null hypothesis of equal correlation matrices for summated scores in Groups 1 through 4 could not be rejected [$\chi^2(18)=16.26$, $P=.57$], sample sizes of the four groups as reported in Table 1. The values from the reasoning tests of the four groups can therefore be pooled to compute correlations and covariances, regardless of test form and test sequence.

Contrary to the expectations of Vernon et al. (1985), the correlation of mental speed and speeded reasoning is stronger than the correlation of mental speed and unspeeded reasoning. This clearly is at odds with the notion of a speed-dependent working memory, and in accordance with the two functions view. A test for the difference of these dependent correlations according to the method proposed by Steiger (1980) resulted in $t(274)=3.46$, $P<.001$, indicating a substantial difference in the direction suggested by the two functions view.

To test the second prediction from the two functions view, namely a lower correlation of speeded and unspeeded reasoning in comparison to the correlation of two speeded reasoning tests, the correlation between the (speeded) reasoning tests in Groups 5 and 6 was computed,[4] as a standard of comparison for the value reported in Table 4. The correlation of the two reasoning tests in Groups 5 and 6 was .79 ($n=90$). A test for the difference of correlations of independent groups (Cohen & Cohen, 1983) resulted in a significant difference, $z=2.55$, $P=.005$ (one-tailed).

3.3. Confirmatory factor analyses

To supplement findings from correlational analyses, confirmatory techniques were employed to assess the relationships between mental speed and speeded and unspeeded reasoning. Instead of using summated standardized scores, parcels were used as indicators for the factors. All parcels were heterogeneous with respect to the content facet but homogeneous concerning operations. As a first step, variance–covariance matrices of parcels for all four groups were tested for equality, resulting in $\chi^2(84)=103.32$, $P=.07$, indicating that the matrices do not differ across groups. The first model, depicted in Fig. 1, mirrors the correlational results reported above as a confirmatory factor analysis.

As shown in Fig. 1, correlations between factors are generally higher than correlations based on summated scores, which is due to disattenuation of relationships from measurement error. The order of correlations between factors is the same as those of the correlations reported in Table 4 with speeded reasoning and unspeeded reasoning showing the strongest, and unspeeded reasoning and mental speed showing the weakest relationship. To test for the

[4] This correlation was based on unweighted composites of standardized scores across *all* groups for both tests. Inclusion or exclusion of Groups 5 and 6 for standardization of scores did not alter any of the conclusions drawn here.

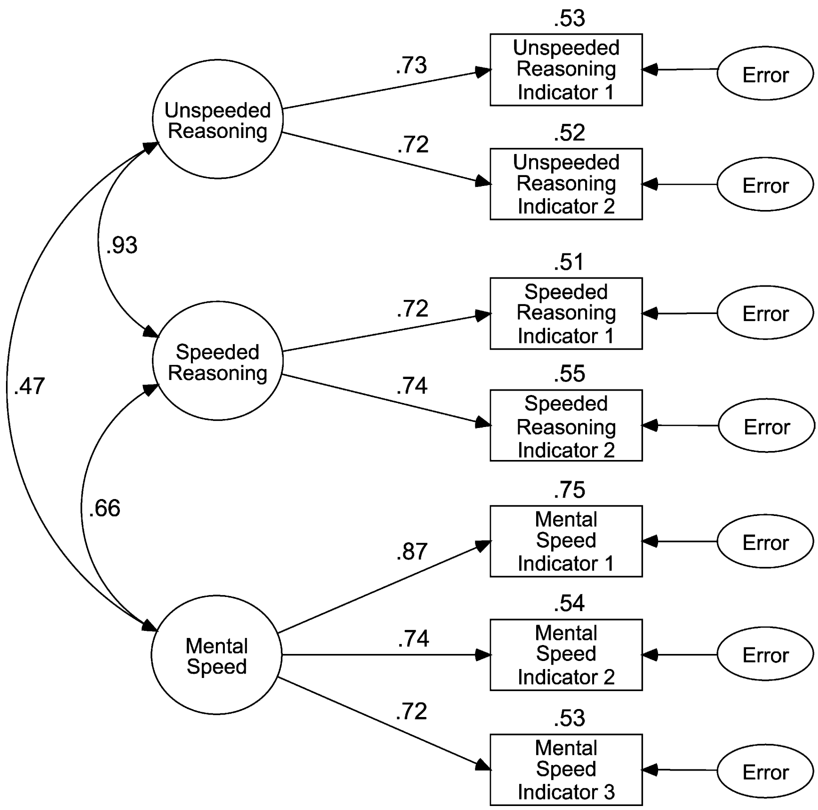

Fig. 1. CFA of correlated reasoning and mental speed factors.

difference between correlations of mental speed with the two reasoning factors, Model 1 was compared with a second model in which these two correlations were constrained to be equal. The importance of this second model lies in the fact that it translates the correlational structure between mental speed versus speeded and unspeeded reasoning as proposed by Vernon and Kantor (1986) in a test of correlations between factors. In other words, this procedure mirrors the test of differences between correlations based on aggregated subtests in the previous subsection with disattenuated correlations between factors. The second model is not as good as Model 1, indicated by the χ^2 difference between Model 1 and 2 of $\chi^2_{diff}(1)=9.71$, $P=.002$. Details of goodness-of-fit statistics for both models are shown in Table 5.

We conclude, that there is a clear ordering of correlation coefficients that is in contradiction to the propositions of Vernon and Kantor (1986) and more in accordance with a theoretical conception that posits two cognitive functions explaining observed variance of speeded reasoning scores. According to this latter view, speeded reasoning scores are conceived as a compound of unspeeded reasoning ability and mental speed. To convert this theoretical proposition into an empirically testable model using the same indicators of factors as in Models 1 and 2, we modeled speeded reasoning ability as a linear function of unspeeded

Table 5
Indices of goodness-of-fit for structural equation models

Statistic	Model		
	1	2	3
χ^2	18.98	28.69	19.77
df	11	12	12
$P(\chi^2)$	.061	.004	.072
Bollen–Stine bootstrapped[a] *P*	.055	.005	.059
CFI	0.989	0.976	0.989
AGFI	0.951	0.935	0.954
RMSEA	0.051	0.071	0.048
90% Confidence interval for RMSEA	0.000–0.089	0.038–0.105	0.000–0.085

[a] Based on 1000 bootstrap samples.

reasoning ability and mental speed. Although this change from a simple correlational model to a regression model bears significant theoretical and interpretational implications, it should be noted that the regression model is actually equivalent to Model 1 in Table 5 in terms of goodness of fit criteria. It can therefore be distinguished from Model 1 only with respect to interpretability of parameter estimates and meaningfulness of the model (MacCallum, Wegener, Uchino, & Fabrigar, 1993). A more stringent test of the two functions hypothesis stated above is the formulation of Model 3 shown in Fig. 2.

Here, the variance of the disturbance term in the regression model is set to zero to ensure that there is no unexplained variance left in speeded reasoning ability. In accordance with the

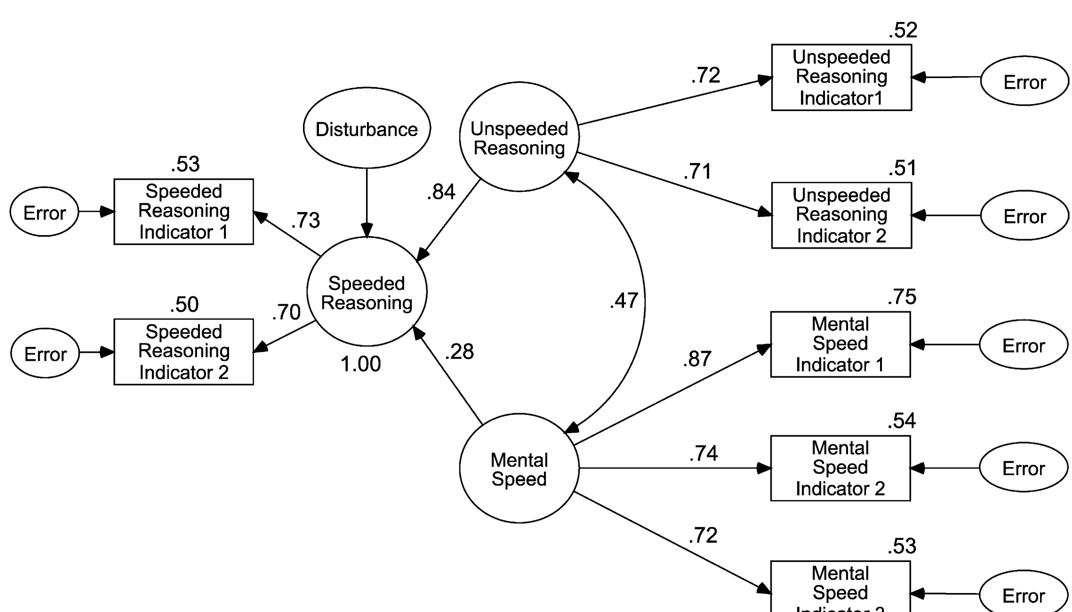

Fig. 2. Structural model relating timed reasoning to mental speed and untimed reasoning.

two functions view, this additional constraint corresponds to the rather restrictive hypothesis that variability in speeded reasoning can be fully explained by interindividual differences in unspeeded reasoning and mental speed. The results for Model 3 shown in Table 5 indicate that this is an acceptable model to explain the observed covariance structure. Because this model is more restrictive than Model 1, as indicated by the additional degree of freedom, and represents a more adequate representation of the theoretical propositions it is favored over Model 1.

In sum, confirmatory factor analyses and correlational analyses led to converging conclusions. There is a clear ordering of linear relationships between mental speed and speeded and unspeeded reasoning. Moreover, a structural model that mirrors the assumptions of the two functions view was successfully tested to fully explain variability in speeded reasoning. Interestingly, unspeeded reasoning and mental speed show a significant and substantial correlation in all models. This is taken as clear evidence of the relationship between these two abilities that is not explainable only through measurement artifacts originating from timed administration of reasoning tests.

4. Discussion

The main purpose of this study was to investigate the contribution of mental speed to task performance on reasoning tasks under timed and untimed conditions. The hypotheses guiding this research were supported, and an alternative explanation could be rejected. Relaxing the time constraints in measures of reasoning ability showed the expected effects: Performance increased, the relative proportions of omitted items were substantially reduced, unspeeded reasoning performance was still measured reliably, the correlation between mental speed and reasoning was substantially reduced, and the correlation between speeded and unspeeded reasoning tests was lower than the correlation between two speeded tests. Neither the test that was administrated with relaxed time constraints, nor the sequence of testing could explain the results we reported. The conclusions were supported by correlational analyses, as well as confirmatory factor analyses. Controlling for age in the correlations and the confirmatory models did not alter the conclusions.

The correlation between summated scores of mental speed and unspeeded reasoning ability (.34) remains substantial. The same is true for the standardized coefficients in all confirmatory models (.47). It could be argued that the size of these coefficients is still in support of the view of a speeded working memory. Alternative interpretations that view working memory and not mental speed as basic to human intelligence (Conway, Cowan, Bunting, Therriault, & Minkoff, in press; Süß et al., in press) are more convincing because this view of memory and attention performance has a solid base, both in theoretical conceptions and experimental work.

Research on intelligence structure heavily relies on the properties of the measurement instruments. In addition to intended variance, unintended variance will usually be present in intelligence measurement. In order to improve measurement and our understanding of the results, it is important to be aware of possibly biasing influences. One possible artifact is the influence of time restrictions on the validity of intelligence tests. The simple manipulation of relaxing time constraints in the measurement of reasoning shows that properties of measurement instruments are not stable when conditions of administration are altered. Speeded and unspeeded tests of reasoning ability do not equally tap the same constructs. Removing the time constraints from reasoning measurement removes mental speed variance. Reasoning should be interpreted as a rate-concept (performance per time unit) when measured with strict time constraints and it should be interpreted as a power-concept (difficulty level still mastered) when measured without time constraints. Both concepts might be more distinct from each other than was hitherto believed. The definitions of reasoning ability currently used and discussed do not reflect the distinction that arises with varying time pressure. Describing the reasoning measures we use as "power" or "rate" indicators is not only more appropriate and precise than ignoring the aspects of time pressure, but it might also help us to deepen the understanding of the measures we are using.

The results reported here show that part of the relationship between mental speed and speeded reasoning ability is due to the timed administration of reasoning measures. Since the strictness of time constraints in most reasoning tests varies, some recommendations can be made.

In research that focuses on the size of the relations between mental speed and reasoning ability, attention should be paid to the complexity of mental speed measures, as well as the time constraints of reasoning measures to avoid overestimation of the relationship between the constructs. The relationship between mental speed tasks and unspeeded reasoning tasks is a better estimate of the true correlation between both abilities because it removes the biasing influence present in time restricted measurement of reasoning ability.

In applied settings, the selection of speeded or unspeeded tests should depend on the purpose of testing. If the construct purity of measurement is of particular importance, unspeeded reasoning would seem to be the better choice. If predictive validity is of particular importance, speeded reasoning ability could be the better choice, especially if the criteria show similar time pressure on performance. If efficient measurement is important to a test user, speeded reasoning almost certainly should be preferred. On the other hand, the costs of psychological measurement frequently can be neglected compared to the benefits. However, the gain in testing time could be used to measure additional predictors, thereby possibly increasing validity again (Johnson & Zeidner, 1991).

Several questions could not be addressed in the present study. The proposed two functions view predicts that the correlation between unspeeded reasoning ability and mental speed should be further reduced when simple measures of mental speed are used. Following the two functions view, mental speed measures that do not tap working memory capacity could be considered suitable tasks. The mental speed tasks used in this study cover a wide range of complexity. However, replication of the current results with a selection of mental speed tests covering the lower end of complexity is warranted before more general conclusions can be drawn. A second topic that awaits research is a test of the hypothesis of whether unspeeded reasoning ability is, indeed, more closely related to working memory capacity than speeded reasoning. Finally, the validity of reasoning-as-rate and reasoning-as-power should be explored in the context of typical behavior, too. For example, traits like complex problem solving, persistence, and conscientiousness could be more closely related to unspeeded reasoning, whereas a trait like "typical work speed" or "test taking speed" could be more closely related to speeded reasoning.

Appendix A. Means, variance–covariance, and correlation matrix for parcels

	SR1	SR2	UR1	UR2	MS1	MS2	MS3
SR1	2.941	.529	.493	.501	.399	.314	.300
SR2	1.676	3.418	.500	.470	.460	.392	.329
UR1	1.658	1.814	3.853	.527	.275	.188	.149
UR2	1.597	1.612	1.923	3.449	.371	.233	.313
MS1	1.430	1.778	1.129	1.438	4.366	.629	.627
MS2	1.169	1.573	.799	.939	2.851	4.704	.554
MS3	1.088	1.286	.617	1.227	2.768	2.540	4.465
Mean	− 1.2093	− 1.2440	1.2093	1.2440	0	0	0

Note: Correlations above, covariances below, and variances on the main diagonal. Values were computed from Groups 1–4 ($n = 277$). SR = speeded reasoning; UR = unspeeded reasoning; MS = mental speed.

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