Processing of Temporal and Nontemporal Information as Predictors of Psychometric Intelligence: A Structural-Equation-Modeling Approach

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ABSTRACT Recent research suggests a functional link between temporal acuity and general intelligence. To better understand this relation, the present study took advantage of a large sample ($N = 260$) and structural equation modelling to examine relations among temporal acuity, measured by various tasks, speed of information processing as measured by the Hick reaction time task, and psychometric intelligence. Temporal acuity and the Hick task showed common variance in predicting psychometric intelligence. Furthermore, timing performance was a better predictor of psychometric intelligence and mediated the relation between Hick task performance and psychometric intelligence. These findings are consistent with the idea that temporal acuity reflects a basic property of neural functioning that is relevant to intelligence-related aspects of mental activity including speed of information processing.

INTRODUCTION

There is a large literature demonstrating a relation between higher mental ability and faster speed and efficiency of information processing on simple sensory, memory, and decision tasks (e.g., Deary, 2000a, 2000b; Jensen, 2004; Vernon, 1987). The most frequently used

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elementary cognitive tasks (ECTs) in this field include inspection time (Vickers, Nettelbeck, & Willson, 1972), simple and choice reaction time following the rationale of Hick (1952), Sternberg's short-term memory scanning (Sternberg, 1969), and Posner's letter-matching task (Posner & Mitchell, 1967). Current explanations for the observed relationship between psychometric intelligence and measures obtained from ECTs usually refer to the concept of "neural efficiency" as being responsible for faster and less error-prone information processing in individuals with high mental abilities (cf. Bates, Stough, Mangan, & Pellett, 1995; Neubauer, 2000; Sternberg & Kaufman, 1998; Vernon, 1993). In the absence of direct and uncontaminated measures of neural mechanisms, ECTs are often used as surrogates for direct neural measurement (McCrory & Cooper, 2005; Nettelbeck & Wilson, 2005). This procedure is based on the idea that these microlevel tasks are so basic as to eliminate the influence of strategy and educational contaminants, with the result that individual differences in performance can primarily be ascribed to differences in underlying neural processes (McCrory & Cooper, 2005).

The Temporal Resolution Power Hypothesis

In recent work, Rammsayer and Brandler (2002) extended this research by showing that higher mental ability was also related to greater accuracy on several measures of timing performance, specifically the discrimination of tones in the range of seconds and milliseconds, temporal-order judgment, and auditory flutter fusion. In a subsequent study (Rammsayer & Brandler, 2007), this effect was replicated in analyses that involved an expanded battery of timing and mental ability tasks as well as the Hick paradigm, a traditional ECT that measures speed of information processing. Notably, a timing factor predicted a greater proportion of variance in general intelligence (31%) than did a Hick factor (12%). The timing and Hick factors also shared variance, and the common variance predicted about 11% of the variance in general intelligence. This observation led to the question of whether timing ability reflects a process that is fundamental to performance on both general intelligence and speed-related tasks. We pursued this question here.

Rammsayer and Brandler's research (2002, 2007) was based on the idea that temporal accuracy as assessed by psychophysical timing tasks—in analogy to performances on ECTs—might reflect basic processes related to neural efficiency. A theoretical context for this notion is afforded by the master clock hypothesis outlined by Surwillo (1968), who proposed that the oscillation rate of a hypothetical general clock mechanism in the human central nervous system (CNS) is responsible for the coordination of a wide range of mental activities. According to this view, a high temporal resolution power or a high oscillation rate of a general timing mechanism should influence information processing by leading to shorter task completion times and less interference from distracting sources of information (cf. Lindenberger, Mayr, & Kliegl, 1993; Rammsayer & Brandler, 2002; Salthouse, 1991). According to this temporal resolution power hypothesis, then, temporal resolution would be associated with better abilities in both speeded and unspeeded mental ability tests, and might, in turn, be a fundamental contributor to psychometric intelligence.

The Present Study

The present study had two concerns: (1) to provide further evidence for the predictive power of timing performance as a new correlate of psychometric intelligence and (2) to get a better understanding of the relationships among temporal acuity, speed of information processing, and psychometric intelligence. For each of these three domains, several measures of performance have been employed in order to obtain adequate estimates of the general factors for each set of tasks (cf. Brody, 1992). The relations between these general factors, termed temporal *g*, psychometric *g,* and Hick *g*, were subject to structural-equation-modelling (SEM). Several models (see Figure 1) were tested. First, the question was whether temporal *g* and Hick *g* were systematically correlated (Model 2) or whether they were unrelated predictors (Model 1). If temporal *g* and Hick *g* are related, potential mediating effects will be analyzed in two further models. Model 3 is based on the idea that temporal *g* partly mediates the relation between psychometric *g* and Hick *g*. In Model 4, the question will be whether Hick *g* also mediates the relation between temporal *g* and psychometric *g*. In general, the goal is to determine whether temporal *g* or Hick *g* is a more powerful and proximate contributor to psychometric intelligence.

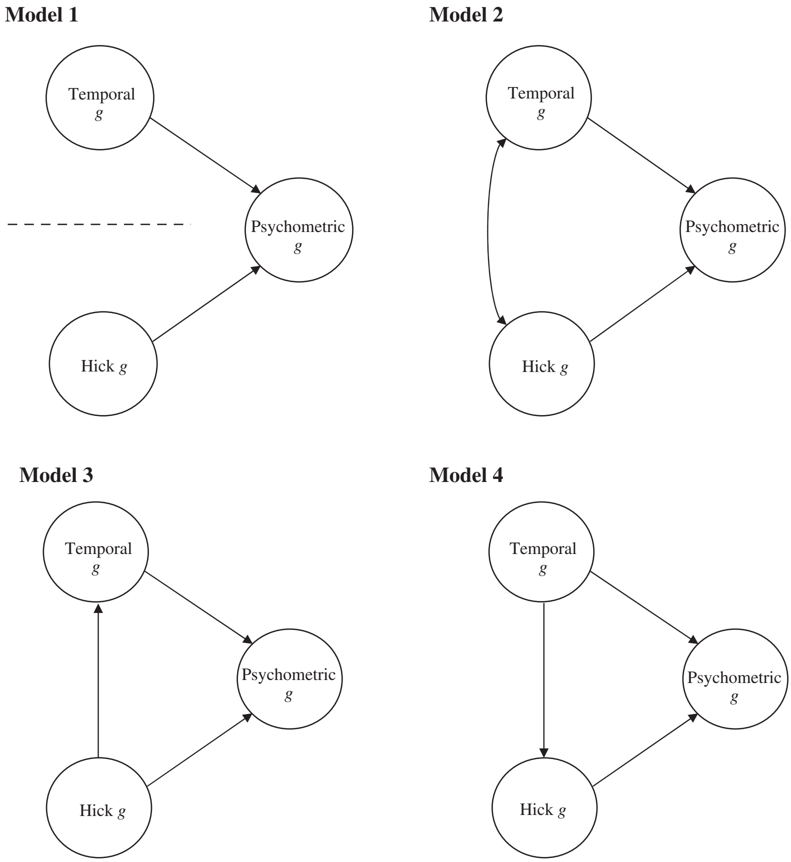

Figure 1

Model 1: Unrelated-predictor model; Model 2: Related-predictor model; Model 3: Model with temporal *g* partly mediating the relationship between Hick *g* and psychometric *g*; Model 4: Model with Hick *g* partly mediating the relationship between temporal *g* and psychometric *g*.

METHOD

Participants

In order to achieve a sample size that provided reliable data for the SEM analyses, the data of Helmbold and Rammsayer (2006) and Rammsayer and Brandler (2002) were pooled. The pooled sample comprised 260 participants (130 male and 130 female). Only younger adults ranging in age from 18 to 39 years (mean ± standard deviation: 24.7 ± 5.5 years) were included in the sample. Education levels spanned a broad range, including 91 university students, 79 vocational school pupils and apprentices, as well as 14 persons who were unemployed. The 76 remaining participants were working persons of different professions. All participants reported normal hearing and had normal or corrected-to-normal sight. They were paid the equivalent of US$30 and offered a feedback about their performance on intelligence testing.

Intelligence Tests

In order to define a valid estimate of psychometric *g*, a comprehensive test battery was employed (cf. Brody, 1992; Jensen, 1998). The battery included 10 intelligence scales assessing various aspects of intelligence corresponding to Thurstone's (1938) primary mental abilities; verbal comprehension, word fluency, space, and flexibility of closure were assessed by subtests of the Leistungsprüfsystem (LPS; Horn, 1983). As a measure of reasoning abilities, the short version of the German adaptation of Cattell's Culture Fair Intelligence Test Scale 3 (CFT; Cattell, 1961) by Weiß (1971) was employed. Furthermore, scales measuring numerical intelligence and verbal, numerical, and spatial memory, respectively, were taken from the Berliner Intelligenzstruktur-Test (BIS; Jäger, Süß, & Beauducel, 1997). A brief description of the components of the battery is presented in Table 1.

Psychophysical Timing Tasks

Because temporal information processing is much more accurate with auditory stimuli than with visual ones, and because auditory stimuli are less prone to task-irrelevant, confounding influences (cf. Grondin, Meilleur-Wells, Ouellette, & Macar, 1998; N'Diaye, Ragot, Garneo, & Pouthas, 2004; Schab & Crowder, 1989), only auditory experimental tasks were used to measure timing-related abilities. Performance measures on interval timing, rhythm perception, and bimodal temporal-order judgment were obtained as psychophysical indicators of temporal resolution.

Interval timing I: Duration discrimination. With this type of task, the participant has to decide which of two successively presented intervals—a constant standard interval and a variable comparison interval—is longer. On each trial, the duration of the comparison can be shorter or longer than the duration of the standard interval. In the present study, two types of stimuli, filled and empty intervals, were used. In filled auditory intervals, a tone was presented continuously throughout the interval, whereas

Table 1
Description of the Psychometric Tests Applied for Measuring Primary Mental Abilities

Intelligence Test	Subscale/Ability	Task Characteristics
LPS	Verbal Comprehension (V)	Detection of spelling mistakes in nouns
LPS	Word Fluency (W)	Anagrams
LPS	Space (S)	Three-dimensional interpretation of two-dimensionally presented objects
LPS	Flexibility of Closure (C)	Detection of single elements in complex objects
CFT	Reasoning (R)	Evaluation of figural arrangements based on inductive and deductive thinking
BIS	Number 1 (N1)	Detection of numbers exceeding the preceding number by "three"
BIS	Number 2 (N2)	Solving of complex mathematical problems by means of simple mathematical principles
BIS	Verbal Memory (vM)	Reproduction of previously memorized nouns
BIS	Numerical Memory (nM)	Reproduction of two-digit numbers
BIS	Spatial Memory (sM)	Recognition of buildings on a city map

Note: LPS = Leistungsprüfsystem; CFT = Culture Fair Intelligence Test Scale 3; BIS = Berliner Intelligenzstruktur-Test.

in empty intervals only the onset and the offset of the interval were marked by clicks. In addition, two different base durations were employed, as there is some evidence that timing in the range of seconds and milliseconds might be functionally different to a certain extent (cf. Michon, 1985; Rammsayer, 1999; Rammsayer & Lima, 1991). The "long" base duration, however, was chosen not to exceed 1,200 ms as this duration represents a critical value above which explicit counting becomes a useful timing strategy (Grondin, Meilleur-Wells, & Lachance, 1999).

The duration discrimination task contained one block of filled and one block of empty intervals with a base duration of 50 ms each, as well as one block of filled intervals with a base duration of 1,000 ms. The order of the three blocks was counterbalanced across participants. Each block contained 64 trials and each trial consisted of one standard interval (= base duration) and one comparison interval. The duration of the comparison interval varied according to an adaptive rule referred to as the *weighted up-down procedure* (Kaernbach, 1991; for more details see Rammsayer & Brandler, 2004). As an indicator of discrimination performance, the difference limen (DL; Luce & Galanter, 1963) was determined. In previous studies performed to evaluate the sensitivity of assessment, Cronbach's alpha coefficients were shown to range from .82 to .99 for the duration discrimination tasks (Brandler & Rammsayer, 1999; Rammsayer, 1994; Rammsayer & Brandler, 2001).

Interval timing II: Temporal generalization. With this task, participants were required to identify a standard stimulus of a certain absolute duration among six deviant, nonstandard stimuli of different durations. Two temporal-generalization tasks with base durations of 75 and 1,000 ms, respectively were applied as an alternative measure of interval timing. Each task consisted of a learning and a test phase. In the learning phase, participants were instructed to memorize a standard stimulus duration, which was presented five times. In the subsequent test phase, both the standard and nonstandard stimuli were presented. In each trial the participants had to decide whether or not the presented stimulus was of the same duration as the standard stimulus. The test phase consisted of eight blocks. Within each block, the standard duration was presented twice, while each of the six nonstandard intervals was presented once. The stimuli were sine wave tones presented through headphones at an intensity of 67 dB. In the range of seconds, the standard stimulus duration was 1,000 ms, and the nonstandard durations were 700, 800, 900, 1,100, 1,200, and 1,300 ms. In the range of milliseconds, the nonstandard stimulus durations were 42, 53, 64, 86, 97, and 108 ms, and the standard duration was 75 ms.

As a quantitative measure of performance, an individual index of response dispersion (cf. McCormack, Brown, Maylor, Darby, & Green, 1999) was computed. For this purpose, the relative frequency of "standard" responses to the standard duration (e.g., 1,000 ms) was divided by the sum of the relative frequencies of "standard" responses to all seven stimulus durations. This measure would approach 1.0 (= best possible performance) if the participant only produced "standard" responses to the standard duration and no standard responses to the nonstandard stimuli. Although many recent studies of human timing have used temporal generalization tasks, the reliability of this type of task, to our knowledge, has not been reevaluated yet.

Temporal-order judgment. Temporal-order judgment refers to the question of how much time must intervene between the onsets of two different stimuli—for example, a tone and a light—for their order to be perceived correctly. Hence, for the temporal-order judgment task, auditory and visual stimuli were employed. Auditory stimuli were 1,000-Hz square waves presented via headphones at an intensity of 67 dB. Visual stimuli were generated by a red light-emitting diode in a black viewer box. The temporal-order judgment task was divided into two independent series of 32 trials each. In Series 1 the tone was preceded by the light, while in Series 2 the tone was presented first. Presentation of both stimuli was simultaneously terminated 200 ms after the onset of the second stimulus. Participants were required to decide whether the onset of the tone or the onset of the light occurred first. Trials from both series were presented randomly. Within each series, stimulus onset asynchrony varied from trial to trial depending on the participant's previous response according to the weighted up-down procedure that converged on a level of 75% correct responses. As an indicator of performance, the difference limen was determined. Rammsayer and Brandler (2002) reported a test-retest reliability coefficient of $r = .73$ for the temporal-order judgment task.

Rhythm perception. In psychophysical rhythm perception tasks, participants have to detect a deviation from regular, periodic, click-to-click intervals. In the present task, the stimuli consisted of 3-ms clicks presented through headphones at an intensity of 88 dB. Participants were presented with auditory rhythmic patterns, each consisting of a sequence of six 3-ms clicks marking five beat-to-beat intervals. Four of these intervals were of a constant duration of 150 ms, while one interval was variable ($150\,\text{ms}+x$). The participant's task was to indicate whether he or she had perceived a deviation from isochrony in the rhythmic pattern (i.e., one beat-to-beat interval was perceived as deviant) or not (i.e., all beat-to-beat intervals appeared to be of the same duration). Task difficulty was adapted by changing the magnitude of x from trial to trial depending on the participant's previous response. The adaptive rule was based on the weighted up-down procedure that converged on a probability of hits of .75. As an indicator of performance, the 75% threshold was determined based on 64 trials. In a previous study (Brandler & Rammsayer, 2000), a test-retest reliability coefficient of $r = .87$ was obtained for the rhythm perception task.

Hick Reaction Time Paradigm

As a measure of speed of information processing a typical ECT, the so-called Hick reaction time (RT) paradigm was used. The Hick paradigm is a visual simple and choice RT task in which participants have to react as quickly as possible to an upcoming visual stimulus. This task is based on

Hick's (1952) discovery of a linear relationship between an individual's RT and the number of stimulus alternatives among which a decision has to be made. In the case of simple RT, no decision between stimulus alternatives is involved (i.e., zero bits of information have to be processed). Analogously, deciding between two stimuli (two-choice RT) requires one binary decision, while, when four alternatives are presented (four-choice RT), two binary decisions are necessary (2-bit). The current version of the Hick paradigm was similar to the one proposed by Neubauer (1991), who was concerned with creating a version of this paradigm that is free of potential confounds such as order effects, response strategies, or changes in visual attention (Longstreth, 1984; Neubauer, Riemann, Mayer, & Angleitner, 1997).

Stimuli were rectangles (2 cm × 1 cm) and a plus sign (0.8 cm) displayed on a monitor screen. In the 2-bit condition (four-choice RT), four rectangles arranged in two rows were presented. After a variable foreperiod varying randomly between 700 and 2,000 ms, the imperative stimulus, the plus sign, was presented randomly in one of the four rectangles. The participants had to respond as quickly as possible to the imperative stimulus by pressing the response button on a "finger-on-keys" apparatus corresponding to the rectangle with the imperative stimulus. After each correct response, a 200-ms tone was presented followed by an intertrial interval of 1,500 ms. The 1-bit condition (two-choice RT) was identical to the 2-bit condition, except that two rectangles were presented arranged in a row. Accordingly, the participant had to choose between two response keys. Similiarly, in the 0-bit condition (no-choice or simple RT), only one rectangle was presented in the center of the screen and the participant had to react by pressing one designated response button. Each condition consisted of 32 trials preceded by 10 practice trials. Order of conditions was randomized across participants. As indicators of individual performance, median RT and intraindividual variability (standard deviation) were computed separately for the 0-, 1-, and 2-bit conditions.

Time Course of the Study

The intelligence tests and experimental tasks were implemented in two testing sessions of 90 minutes each. The order of testing sessions was counterbalanced across participants. Both testing sessions were separated by a 1-week interval. The experimental session was initiated by the three duration discrimination tasks, followed by temporal generalization, the temporal-order judgment task, rhythm perception, and the Hick task. Experimental trials of all tasks were preceded by practice trials to ensure that the participants understood the instructions and to familiarize them with the stimuli.

Data Analysis

For confirmatory factor analysis (CFA) and SEM analyses, Muthén and Muthén's (2005) M*plus* software and maximum likelihood methods were applied in the present study.

RESULTS

Descriptive Statistics

Descriptive statistics for all performance measures are presented in Table 2.

Confirmatory Factor Analysis: Specification of the Measurement Models

According to current factor-analytic conceptions of intelligence (cf. Carroll, 1993; Jensen, 1998; Johnson & Bouchard, 2005), psychometric *g* was conceptualized as a higher-order factor emerging at the top of a hierarchical model of several lower-order mental abilities. Modeling was based on the Berlin Intelligence Structure Model developed by Jäger (1982, 1984). According to this model, psychometric intelligence was extracted as a second-order factor based on the three first order factors of speed, processing capacity, and memory, each of which was operationalized in several ways. Residuals from subtests assigned to the same content category were allowed to covary as indicated by the corresponding arrows in the path diagrams. This model yielded a satisfactory degree of fit ($\chi^2 = 33.79$, $df = 20$, $p = .028$, CFI = .98, TLI = .96, RMSEA = .05).

The Hick data was also modeled in a hierarchical model with Hick *g* as second-order factor and central tendency of RT and intraindividual variability of RT as first-order factors. Extraction of these two first-order factors was based on considerations in the literature, which suggest that both these measures of RT reflect different aspects of information processing performance (cf. Deary & Caryl, 1997; Jensen, 1992, 2004; Slifkin & Newell, 1998). Because, at the same bit level, central tendency and intraindividual variability of RT cannot be considered independent of each other, residuals from both parameters were allowed to covary at each level of task complexity. Also for this model, an acceptable degree of fit was

Table 2
Mean (*M*), Standard Deviation (*SD*), Minimum (*Min*), and Maximum (*Max*) of All Performance Measures Obtained

Performance Measure	*M*	*SD*	*Min*	*Max*
Intelligence tests				
Verbal Comprehension [test score]	23.5	6.6	6	38
Word Fluency [test score]	29.4	8.0	5	40
Space [test score]	29.0	6.0	7	40
Flexibility of Closure [test score]	32.1	6.1	13	40
Reasoning [test score]	26.1	5.3	7	38
Number 1 [test score]	22.6	7.3	1	40
Number 2 [test score]	4.0	2.2	0	7
Verbal Memory [test score]	8.2	2.4	3	18
Numerical Memory [test score]	7.4	2.2	1	14
Spatial Memory [test score]	15.5	4.6	4	27
Temporal tasks				
DD1 [DL in ms]	9.6	5.6	3.3	51.4
DD2 [DL in ms]	18.7	9.3	4.1	70.8
DD3 [DL in ms]	150.1	81.4	44.2	745.0
TG1 [IRD]	.35	.11	.10	.73
TG2 [IRD]	.32	.11	.08	.78
TOJ [DL in ms]	93.0	32.6	22.9	200.2
RP [75%-threshold in ms]	54.9	20.2	6.1	142.4
Hick parameters				
RT 0 bit [ms]	244	32.1	179	355
RT 1 bit [ms]	308	38.4	227	460
RT 2 bit [ms]	390	58.5	269	581
RTSD 0 bit [ms]	65	28.3	21	164
RTSD 1 bit [ms]	58	23.4	23	221
RTSD 2 bit [ms]	75	26.8	30	298

Note: DD1 = duration discrimination of filled intervals (base duration = 50 ms); DD2 = duration discrimination of empty intervals (base duration = 50 ms); DD3 = duration discrimination of filled intervals (base duration = 1,000 ms); TG1 = temporal generalization (base duration = 75 ms); TG2 = temporal generalization (base duration = 1,000 ms); TOJ = temporal-order judgment; RP = rhythm perception; DL = difference limen; IRD = index of response dispersion; RT = median reaction time; RTSD = intraindividual standard deviation of reaction time.

obtained ($\chi^2 = 12.94$, $df = 5$, $p = .024$, CFI = .99, TLI = .96, RMSEA = .08).

Modeling of the data of temporal information processing was based on prior factor-analytic findings suggesting that performance on the several temporal tasks employed in the present study can exhaustively be described by a single general factor at the first level of aggregation (Rammsayer & Brandler, 2004, 2007). Therefore, based on all seven temporal measures, the first principal factor was extracted by means of CFA, referred to as temporal *g*. This model represented the data very well ($\chi^2 = 13.89$, $df = 14$, $p = .46$, CFI = 1.00, TLI = 1.00, RMSEA = .00).

Structural Equation Modelling: The Issue of Relatedness

A first issue is whether Hick *g* and temporal *g* are related to each other, a question that contrasts Model 1 (independence of predictors) with Model 2 (correlated predictors). As can be seen from Table 3, the unrelated-predictor model (Model 1) did not represent the data adequately, whereas for the related-predictor model (Model 2; see Figure 2), an acceptable degree of fit was observed. A significant χ^2 difference between both these nested models ($\Delta\chi^2 = 59.31$, $df = 1$, $p < .001$) clearly favored Model 2, which assumes a functional relationship between temporal *g* and Hick *g*.

Of further importance are the path coefficients in both models. In the unrelated-predictor model (Model 1), the path coefficient describing the direct effect from Hick *g* to psychometric *g* was $-.25$ ($t = -4.20$, $p < .001$), whereas the coefficient relating temporal *g* and psychometric *g* was .59 ($t = 11.59$, $p < .001$). When allowing both predictors to correlate (Model 2), a significant correlation of $-.65$ ($t = -13.81$, $p < .001$) between Hick *g* and temporal *g* was observed. With the correlation among predictors controlled, temporal *g* remained a highly significant independent predictor of psychometric *g* (estimated path coefficient = .59, $t = 11.65$, $p < .001$), whereas this was not true of the Hick *g* path coefficient ($t = -1.79$, $p = .07$). Thus, there is some initial indication that Hick *g* predicts psychometric *g* due to its shared variance with temporal *g*, whereas temporal *g* has independent predictive value.

Structural Equation Modeling: The Issue of Mediating Effects

Possible mediating effects among the predictors were examined in Models 3 and 4 (cf. Tabachnick & Fidell, 2001). Model 3 was supported because temporal *g* significantly mediated the relation between Hick *g* and psychometric *g* ($t = -6.64$, $p < .001$). This indirect

Table 3
Summary of Fit Statistics for Structural Equation Models

Model	χ^2	*df*	*p*	CFI	TLI	AIC	RMSEA
Model 1							
Unrelated-predictor model	384.54	209	.000	.90	.88	39720.66	.06
Model 2							
Related-predictor model	325.23	208	.000	.94	.92	39663.35	.05
Model 3							
Hick *g*—psychometric *g* partly mediated by temporal *g*	325.23	208	.000	.94	.92	39663.35	.05
Model 4							
Temporal *g*—psychometric *g* partly mediated by Hick *g*	325.23	208	.000	.94	.92	39663.35	.05
Model 5							
Hick *g*—psychometric *g* totally mediated by temporal *g*	325.87	209	.000	.94	.92	39661.99	.05
Model 6							
Hick *g* and temporal *g* related to speed, capacity, and memory	319.11	204	.000	.94	.92	39665.22	.05

Note. CFI = Comparative Fit Index; TLI = Tucker-Lewis Index; AIC = Akaike Information Criterion; RMSEA = Root Mean Square Error of Approximation.

effect was more pronounced than the direct effect of Hick *g* on psychometric *g,* which did not reach statistical significance in the mediation analysis. By contrast, Model 4 found that, with temporal *g* controlled, Hick *g* had no direct implications for predicting psychometric *g*. Furthermore, Hick *g* had no significant mediating influence on the relation between temporal *g* and Hick *g* ($t = 1.14$, $p = .25$).

To further elucidate the mediating effect of temporal *g* on the relationship between Hick *g* and psychometric *g,* an additional model was tested. Model 5 was based on the assumption that Hick *g* only predicts psychometric *g* because of shared variance between Hick *g* and temporal *g*. This model resembles Model 3 but does not include a direct link between Hick *g* and psychometric *g* (see Figure 3). Though being somewhat more parsimonious, Model 5 fitted the data

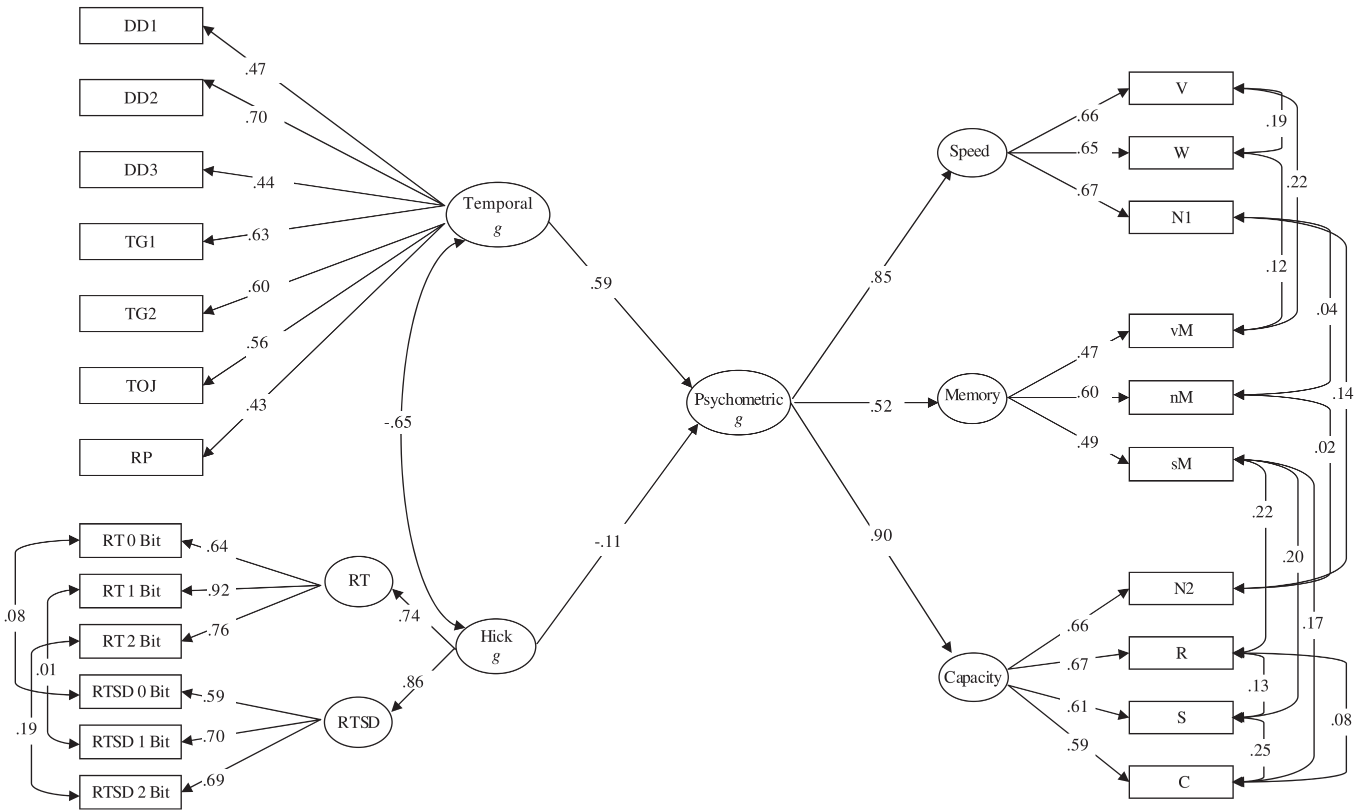

Figure 2
Related-predictor model (Model 2).

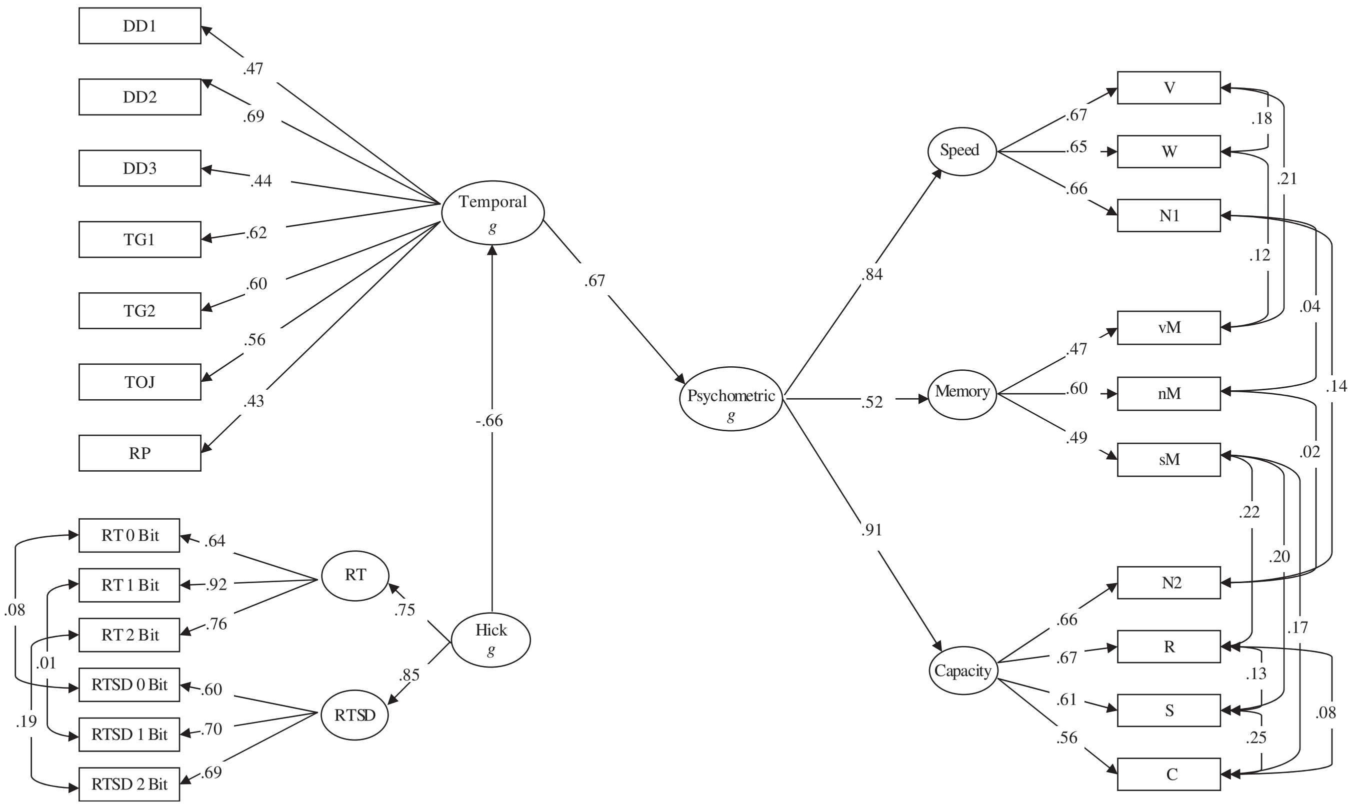

Figure 3
Model with temporal *g* totally mediating the relationship between Hick *g* and psychometric *g* (Model 5). (For abbreviations, see Tables 1 and 2).

as well as Model 3 (see Table 3). Deletion of the direct link from Hick *g* to psychometric *g* did not lead to a significant loss of model fit ($\Delta\chi^2 = .64$, $df = 1$, $p > .05$).

Additional Analyses Involving First-Order Factors of Intelligence

A final analysis (referred to as Model 6) decomposed psychometric *g* into its constituent factors related to speed, capacity, and memory ability. Because this model does not focus on possible mediating effects, a correlational relationship between temporal *g* and Hick *g* was assumed. Furthermore, the first-order factors of intelligence were allowed to correlate. This model obtained a satisfactory fit (see Table 3). Temporal *g* showed significant direct effects on each of the three first-order factors: speed (estimated path coefficient = .39, $t = 6.82$, $p < .001$), memory (estimated path coefficient = .54, $t = 10.17$, $p < .001$), and capacity (estimated path coefficient = .60, $t = 11.89$, $p < .001$). In contrast, Hick *g* proved to be exclusively related to the speed factor (estimated path coefficient = −.22, $t = -3.61$, $p < .001$). The path coefficients relating Hick *g* to memory (estimated path coefficient = .07, $t = 1{,}14$, $p = .25$) and capacity factors (estimated path coefficient = −.02, $t = -.32$, $p = .75$) were not significant.

DISCUSSION

The present study was designed to investigate the functional relationship between temporal acuity, speed of information processing as measured by the Hick paradigm, and psychometric intelligence. A large sample size and SEM procedures allowed us to make more definitive statements concerning relations between these constructs. The results illuminated the central role of temporal acuity as a predictor of psychometric intelligence, at least relative to the speed parameters assessed by the Hick paradigm. Implications of these results are discussed next.

Temporal Acuity and Information Processing Speed as Predictors of Psychometric Intelligence

SEM analyses reinforce some prior suggestions related to relations between basic cognitive performance and more general measures of intellectual performance. Replicating previous results, performance on both tasks of temporal information processing (Rammsayer &

Brandler, 2002, 2007; Watson, 1991) and the Hick paradigm (Deary, 2000a; Jensen, 1987, 2004, Juhel, 1991; Vernon, 1987) predicted individual differences in psychometric intelligence. The present findings also confirm the suggestions of Rammsayer and Brandler (2007) that temporal *g* may be more predictive of psychometric intelligence than are simple reaction times of the sort examined in the Hick paradigm. Perhaps of more importance, the large sample size and SEM approach used here allowed us to further this literature in several ways.

We were able to show that temporal acuity and information processing speed are correlated rather than independent factors. Such a substantial correlation further allowed us to characterize the independent predictive value of temporal *g* and Hick *g*, and in this context it was found that only temporal *g* was a significant predictor of psychometric intelligence when variance common to temporal *g* and Hick *g* were controlled for. These findings point to a mediating effect of temporal *g* on the relationship between Hick *g* and psychometric *g,* which was further examined in Model 3. As hypothesized, Model 3 results showed that the indirect path of Hick *g* on psychometric *g* (as mediated by temporal *g*) was larger than the direct or unmediated relation between Hick *g* and psychometric *g*. These results are consistent with the idea that temporal acuity is the more important variable in relation to psychometric intelligence and indeed appears to be sufficient to account for the well-replicated effects linking speed of information processing to the general intelligence-related abilities of the individual.

A more definite idea of a hierarchical relationship between temporal resolution power and mental speed was supported by Model 5, which was based on the assumption that the relationship between Hick *g* and psychometric *g* is entirely mediated by temporal *g*. Although this model, relative to Model 3, was more parsimonious, it provided an equal fit to the data. Thus, the present data provide a strong case for the idea that temporal abilities, relative to mere mental speed, are a more important predictor of performance on general intelligence tests (Rammsayer & Brandler, 2007).

This interpretation was corroborated by the finding that temporal acuity is significantly related to various aspects of psychometric intelligence as reflected by the first-order factors of intelligence referred to as speed, capacity, and memory. This outcome is in line with the results from a previous study (Helmbold & Rammsayer, 2006) demonstrating that timing performance is significantly associated with both speed and power/capacity measures of intelligence.

Study Limitations and Suggestions for Future Research

Some limitations of the present study, which in turn have implications for future research in this area, should be addressed. First, with regard to the reported superiority of timing performance over speed of information processing in predicting psychometric *g*, it should be noted that timing acuity was assessed by several temporal tasks, but speed of information was measured only by one task—the Hick paradigm. Because composite scores of performance will have more general and less specific variance if based on a large number of distinct tasks (Brody, 1992; Jensen, 1998), it cannot be excluded that superiority of temporal *g* in predicting psychometric *g* might be biased by the fact that this compound measure was based on a more diverse battery of tasks than Hick *g*. Therefore, further studies comparing timing acuity and speed of information processing as predictors of psychometric *g* should be based on more equivalent batteries of different tasks.

A second point concerns potential effects of sex and age on the relationship between both nonpsychometric domains and psychometric intelligence. Unfortunately, our sample size was too small to perform SEM for males and females separately. Therefore, future studies addressing this topic would be useful. Also, given the rather restricted age range of our participants, additional investigations are necessary to further elucidate the potential moderating effects of age on the relations observed here.

Finally, it is interesting to speculate on some of the other correlates of temporal processing acuity aside from those related to psychometric intelligence. In this connection, several studies have shown that dyslexic individuals have significant deficits in temporal resolution tasks (e.g., Rousseau, Hébert, & Cuddy, 2001; Tallal, Stark, & Mellits, 1985; Wolff, 1993). Also, psychological disorders such as those linked to affect and schizophrenic symptoms have been linked to temporal processing abilities in previous research (e.g., Bschor et al., 2004; Davalos, Kisley, Polk, & Ross, 2003; Rammsayer, 1990). Thus, temporal acuity may be an important personality variable quite aside from its apparent relation with psychometric intelligence. We therefore encourage such research in future studies.

Conclusion

The intelligence literature has displayed a great deal of interest in cognitive processing speed as a predictor of psychometric intelligence. The present study followed this general focus on performance in elementary cognitive tasks but further proposed that temporal acuity, relative to speed of processing, may be the more important elementary ability in predictions of psychometric intelligence. The results were in support of this suggestion. Thus, the present study contributes to the suggestion that more attention should be paid to individual differences in temporal resolution abilities relative to information-processing speed as temporal resolution abilities may be more important to predicting individual differences in intelligence-related abilities.

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