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Performance on temporal information processing as an index of general intelligence

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Abstract

The relation between general intelligence (psychometric *g*) and temporal resolution capacity of the central nervous system was examined by assessing performance on eight different temporal tasks in a sample of 100 participants. Correlational and principal component analyses suggested a unitary timing mechanism, referred to as temporal *g*. Performance on single temporal tasks and individual factor scores on temporal *g* were substantially correlated with factor scores on psychometric *g*. Additional stepwise multiple regression analysis and commonality analysis showed that performance on temporal information processing provides a more valid predictor of psychometric g than traditional reaction time measures derived from the Hick paradigm. Findings suggest that temporal resolution capacity of the brain as assessed with psychophysical temporal tasks reflects aspects of neural efficiency associated with general intelligence.

Keywords: General intelligence; Timing performance; Reaction time; Neural efficiency

By use of cognitive information processing models and methods, our understanding of individual differences in mental ability has been improved considerably over the past three decades. A major experimental approach to elucidate basic cognitive mechanisms underlying general intelligence (psychometric *g*) originated from ideas of Galton (1883, 1908) and Spearman (1904, 1927). This approach is based on the attempt to relate psychometric *g* to speed of information processing (Brody, 1992; Jensen, 1987). Within this conceptual framework, a large number of studies provided evidence indicating a relation between levels of psychometric *g* and certain parameters of reaction time (RT) derived from *Hick's law*. Hick (1952) postulated a linear relationship between the amount of information measured in *bits* and a participant's RT. More specifically, *Hick's law* states a linear increase in RT with the binary logarithm ($\log_2$) of the number (n) of equally likely response alternatives in a visual RT task. This relationship can be expressed as $RT = a + b \log_2 n$ where a is the intercept and b is the slope constant. While the intercept a is usually interpreted as representing an estimate of the time required for sensorimotor processes such as stimulus identification and response execution, the slope b is considered an estimate of the time required for the cognitive processes of stimulus evaluation and response selection (Jensen, 1987).

In 1964, the German psychologist Erwin Roth provided first evidence for the assumption that the slope b of the Hick regression line should negatively correlate with

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psychometric intelligence since high intelligent individuals should need less time than low intelligent individuals to process one bit of information. In a study with 58 participants, Roth (1964) found a correlation of −0.39 between slope constant and a psychometric measure of general intelligence. This was the starting point for a large number of studies relating parameters obtained with the Hick task, such as median RT and individual variation in RT per bit level, the intercept *a* or the slope *b* of the regression line, to psychometric intelligence (for a review, see Jensen, 1987, 1998a). Various efforts to link these parameters, as indicators of speed of information processing, to psychometric intelligence showed rather inconsistent results. Nevertheless, several reviews arrived at the conclusion that uncorrected correlations of these mental speed measures and psychometric *g* average somewhere between 0.20 and 0.30 (e.g., Brody, 1992; Jensen, 1987, 1998a; Neubauer, Riemann, Mayer, & Angleitner, 1997).

Proceeding from the assumption that RT measures provide an index of the speed and efficiency with which the central nervous system processes elementary information, Jensen put forward the idea that the same basic characteristics of brain functioning determine both performance on the Hick task and level of psychometric *g*. According to Jensen's (1980, 1982) model of neuronal oscillations, individual differences in RT and psychometric *g* are considered a function of the rate of oscillation between a refractory and an excitatory state of the neuron. The speed of transmission of neurally encoded information is assumed to be faster and more efficient at a higher rate of neuronal oscillations. This is because with a higher rate of oscillation it will take less time for a neuron to enter the excitatory phase of its cycle when a stimulus is presented during the refractory phase than when oscillations are slow. As a consequence, individuals with a faster oscillation rate are expected to perform better on the Hick paradigm as well as on psychometric intelligence tests. Although the neuronal oscillation model provides a central feature of the relationship between Hick parameters and psychometric *g*, there is little empirical evidence in favor of this model (Brody, 1992).

The notion of an internal master clock represents an alternative metaphor to account for the relationship between efficiency and speed of information processing and psychometric *g*. The concept of a hypothetical master clock has been introduced by Surwillo (1968) to account for age-related cognitive impairment and general slowing. He proposed an internal clock mechanism in the central nervous system for coordination of different neural activities. More recently, Burle and Bonnet (1997, 1999) provided additional converging experimental evidence for the existence of some kind of master clock in the human information processing system.

Surwillo's (1968) basic idea can be transferred easily to the explanation of the relationship between speed of information processing and psychometric *g*. If we assume that the hypothesized internal master clock of individual A works, for example, at half the clock rate as the one of individual B, then A does not only need twice as long as B to perform a specific sequence of mental operations, but also the occurrence probability of interfering incidents will be increased. This should lead to lower performance on both the Hick task and tests for psychometric assessment of intelligence in individual A compared to B.

However, in order for the internal master clock interpretation to receive serious consideration, it must be demonstrated that some measure of clock rate reliably differentiates between individuals of low and high psychometric *g*. One of the most direct measures of internal clock rate represents temporal resolution capacity as indicated by timing accuracy. A large number of models of temporal information processing (e.g., Creelman, 1962; Gibbon, 1991; Rammsayer & Ulrich, 2001; Treisman, Faulkner, Naish, & Brogan, 1990; for a review, see Grondin, 2001) is based on the central assumption of neural oscillations as a major determinant of timing performance. According to this account, the higher the frequency of the neural oscillations the finer the temporal resolution of the internal clock will be, which is equivalent to greater timing accuracy. Furthermore, temporal resolution of the brain, as reflected by performance on genuine temporal tasks, can be considered largely independent of factors unrelated to temporal information processing, such as nontemporal cognitive operations or motor responses. Therefore, measures of timing accuracy appear to be a valid and sensitive behavioral indicator of internal clock speed.

Within the framework of human temporal information processing, the idea of different elementary time experiences such as interval timing, rhythm perception, temporal-order judgment, or simultaneity and successiveness has been put forward by several authors (Block, 1990; Fraisse, 1984; Friedman, 1990; Pöppel, 1978). Although the notion of elementary time experiences has been accompanied by the assumption of distinct timing mechanisms, a major controversy in the field of human timing refers to the question of whether psychological time represents a unitary concept or consists of distinct elementary temporal experiences. While the latter view implies different mechanisms underlying specific temporal experiences, a unitary concept of temporal processing would be consistent with the general idea that temporal information processing depends on a universal timing mechanism referred to as internal master clock. Recent research supported the notion of a common timing mechanism or master clock involved in various kinds of timing tasks (Ivry & Spencer, 2004; Rammsayer & Brandler, 2004). In the following, a brief description of the above mentioned four elementary time experiences will be given.

Interval timing is often explained by the general assumption of a hypothetical internal clock based on neural counting (e.g., Creelman, 1962; Gibbon, 1991; Grondin, 2001; Killeen & Weiss, 1987; Rammsayer & Ulrich, 2001). This means that a neural pacemaker generates pulses and that the number of pulses relating to a physical time interval is recorded by an accumulator. Thus, the number of pulses counted during a given time interval is the internal representation of this interval. Although the concept of neural counting has been a central feature of many theoretical accounts of interval timing, experimental evidence suggests that interval timing is affected by stimulus type and, thus, temporal processing of filled intervals may be functionally different from processing of empty ones (Craig, 1973). In filled intervals, the onset and the offset of a continuous signal serve as markers, whereas an empty interval is a silent duration marked by an onset and an offset signal with no stimulus present during the interval itself. Furthermore, interval timing is also influenced by cognitive factors such as attention (e.g., Brown, 1997; Grondin & Macar, 1992; Zakay & Block, 1996) and memory processes (e.g., Fortin & Breton, 1995; McCormack, Brown, Maylor, Richardson, & Darby, 2002). There is some evidence that these cognitive factors may become more effective for the timing of intervals longer than approximately 500 ms (Michon, 1985; Rammsayer, 1999; Rammsayer & Lima, 1991).

Rhythm perception refers to the subjective grouping of objectively separate events (Demany, McKenzie, & Vurpillot, 1977) or discrimination processes in serial temporal patterns (ten Hoopen et al., 1995). Typically, in psychophysical rhythm perception tasks, the subject is presented with a click pattern, devoid of any pitch, timbre, or dynamic variations to avoid possible confounding influences on perceived rhythm. The subject's task is to detect a deviation from regular, periodic click-to-click intervals. The perception of temporal deviations in isochronous patterns may be accounted for by an interval-based (Keele, Nicoletti, Ivry, & Pokorny, 1989; Pashler, 2001) or beat-based (McAuley & Kidd, 1998; Povel & Essens, 1985) timing mechanism.

Temporal-order judgment (TOJ) refers to the question of how much time must intervene between the onsets of two different stimuli for their order to be perceived correctly. Models of TOJ basically assume that processing of temporal order depends on specific aspects of temporal resolution (e.g., Sternberg & Knoll, 1973; Ulrich, 1987).

Investigations of *simultaneity* and *successiveness* are concerned with the size of the temporal interval between two sensory events that is required for them to be perceived as two separate events (successiveness) rather than fused as one event (simultaneity) (for a concise review, see Fraisse, 1984). Auditory flutter fusion (AFF) thresholds, for example, represent an indicator of this type of temporal resolving power.

In a previous study relating general fluid intelligence to temporal resolution capacity of the brain, Rammsayer and Brandler (2002) showed that combined performance on duration discrimination of brief filled and empty auditory intervals in the range of milliseconds accounted for 22% of the total variance of psychometric performance on Cattell's (1961) Culture Free Test Scale 3 (CFT). Furthermore, exploratory principal component analysis yielded two factors with eigenvalues greater than 1 that explained 56.5% of variance. As indicated by substantial factor loadings ranging from 0.59 to 0.75, the first factor, accounting for 38% of variance, was related mainly to performance on duration discrimination of intervals in the range of seconds and milliseconds, TOJ, and level of general fluid intelligence as measured by CFT scores. The second factor seemed to reflect specifically sensory temporal resolving power as indicated by AFF threshold values and was unrelated to CFT performance. Thus, these preliminary findings may be indicative of a functional relationship between psychometric *g* and temporal resolution capacity of the central nervous system as reflected by different temporal tasks.

The present study was designed to further investigate the possible functional relationship between temporal information processing and psychometric *g*. In this respect, the present study represents an extended replication of Rammsayer and Brandler's (2002) work. Nevertheless, the present study differed from the preceding study in several relevant aspects and addressed some further, fundamental questions.

For example, one major difference between both studies refers to the procedure to obtain a valid measure of psychometric *g*. If psychometric intelligence tests are limited to a small subset of primary mental abilities, then conclusions about psychometric *g* may be unwarranted (Brody, 1992). According to a major corollary of Spearman's (1904) two-factor theory of intelligence, (1) every mental test contains a portion of mental *g* and each mental test contains a different specific factor *s*, and (2) psychometric *g* and *s* are uncorrelated with each other. Therefore, a composite score based on a large number of distinct tests will have relatively more psychometric *g* and less *s* than any of the individual test scores (Jensen, 1998a). Based on these considerations, a psychometric test battery comprising of 14 subtests was employed in the present study to obtain a most valid measure of psychometric *g*.

Furthermore, in order to assess the notion of a positive relationship between temporal accuracy and psychometric *g*, correlational analyses were performed relating performance on eight temporal tasks, rather than only five in the Rammsayer and Brandler (2002) study, to individual factor scores on psychometric *g*.

Then, in a next step, the present study investigated whether there is evidence of a hypothetical master clock providing a task-independent general processing system for various aspects of temporal information. More specifically, a factor-analytic approach was applied to obtain a composite measure of general temporal resolution power referred to as temporal *g*.

Eventually, another question to be answered refers to the relationship among individual levels of psychometric *g*, performance on temporal information processing, and speed of information processing. For this purpose, simple and choice RT following the rationale of Hick (1952) was also assessed in the present study. If, in fact, performance on temporal information processing represents a more direct measure of intelligence-related temporal resolution power of the central nervous system than performance obtained with the Hick paradigm, then the portion of explained variance of psychometric *g* should be substantially larger for the former than for the latter measures of performance.

1. Methods

1.1. Participants

Participants were 40 male and 60 female volunteers ranging in age from 18 to 45 years (mean and standard deviation of age: 26.0±6.8 years). All participants had normal hearing and normal or corrected-to-normal sight. Eighty-one participants were university students, with the remainder drawn from the wider community. A majority of the latter responded to announcements posted at various public announcements boards. All non-student participants were working people of different professions. Before being enrolled in the study, each participant was informed about the study protocol and gave his/her written informed consent. For taking part in this study, participants were paid the equivalent of US$30.00.

1.2. Intelligence tests

A comprehensive intelligence test battery was used for psychometric assessment of different aspects of intelligence corresponding to Thurstone's (1938) 'primary mental abilities'. The test battery was, in part, composed of several subtests (verbal comprehension, word fluency, space, closure, perceptual speed) of the Leistungsprüfsystem (LPS; Horn, 1983), a German intelligence test based on Thurstone's (1938) model of primary mental abilities.

In addition, as a measure of performance on reasoning, the short version of the German adaptation of Cattell's Culture Free Test Scale 3 (CFT; Cattell, 1961) by Weiss (1971) was applied. Individual CFT test scores were obtained on the subscales Series, Classifications, Matrices, and Topologies.

The last part of the test battery consisted of two subtest for numerical intelligence and three subtests for verbal, numerical and spatial memory, respectively, of the Berliner Intelligenzstruktur-Test (BIS; Jäger, Süβ, & Beauducel, 1997).

All intelligence tests were applied in a 90-min testing session. Instructions were given directly before the application of the respective test. A brief description of the psychometric tests is presented in Table 1.

1.3. Experimental tasks

1.3.1. Duration discrimination tasks

Because interval timing may be influenced by type of interval (filled vs. empty) and base duration, the duration discrimination task consisted of 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 1000 ms. Furthermore, when participants are asked to compare time intervals, many of them adopt a counting strategy. Since explicit counting becomes a useful timing strategy for intervals longer than approximately 1200 ms (Grondin, Meilleur-Wells, & Lachance, 1999), the "long" base duration was chosen not to exceed this critical value.

1.3.1.1. Stimuli. Filled intervals were white-noise bursts from a computer-controlled sound generator (Phylab Model 1), presented binaurally through headphones (Vivanco SR85) at an intensity of 67 dB SPL. The empty intervals were marked by onset and offset clicks 3 ms in duration, with an intensity of 88 dB. These intensity levels were chosen on the basis of the results of a prior pilot experiment in which 12 subjects were asked to adjust the loudness of a 3-ms click until it matched that of a 1000-ms white-noise signal.

Table 1
Description of psychometric tests applied for measuring primary mental abilities: the scales are presented in the order of their presentation

Intelligence scale	Number of items	Task characteristics
Verbal comprehension	40	Detection of typographical errors in nouns
Word fluency	40	Anagrams
Space 1	40	Mental rotation
Space 2	40	Three-dimensional interpretation of two-dimensionally presented objects
Closure	40	Detection of single elements in complex objects
Perceptual speed	40	Comparison of two columns of letters and digits
Series	13	Completion of a series of pictures
Classifications	14	Finding two pictures which violate a rule within a set of five pictures
Matrices	13	Completion of a matrix
Topologies	10	Topological reasoning
Number 1	44	Detection of numbers exceeding the proceeding number by 'three'
Number 2	7	Solving of complex mathematical problems by means of simple mathematical principles
Verbal memory	20	Reproduction of previously memorized nouns
Numerical memory	16	Reproduction of two-digit numbers
Spatial memory	27	Recognition of buildings on a city map

1.3.1.2. Procedure. The order of blocks was counterbalanced across participants. Each block consisted of 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 (Kaernbach, 1991) to estimate $x.25$ and $x.75$ of the individual psychometric function, that is, the two comparison intervals at which the response "longer" was given with a probability of 0.25 and 0.75, respectively. In each experimental block, one series of 32 trials converging to $x.75$ and one series of 32 trials converging to $x.25$ were presented. Within each series, the order of presentation for the standard interval and the comparison interval was randomized and balanced, with each interval being presented first in 50% of the trials. Trials from both series were randomly interleaved within a block.

Within each trial, the two intervals were presented with an interstimulus interval (ISI) of 900 ms. The participant's task was to decide which of the two intervals was longer and to indicate his or her decision by pressing one of two designated response keys. After each response, visual feedback ("+", i.e., correct; "−", i.e., false) was displayed on the computer screen. The next trial started 900 ms after the feedback. As an indicator of discrimination performance, half the interquartile ranges [(75%-threshold value − 25%-threshold value) / 2], representing the difference limen, DL (Luce & Galanter, 1963), was determined for each duration discrimination task.

In previous studies, performed to evaluate the sensitivity of assessment, Cronbach's α coefficients were shown to range from 0.82 to 0.99 for the duration discrimination tasks (Brandler & Rammsayer, 1999; Rammsayer, 1994; Rammsayer & Brandler, 2001).

1.4. Temporal generalization tasks

In addition to the duration discrimination tasks, two temporal generalization tasks were used with base durations of 75 and 1000 ms, respectively. Unlike duration discrimination, temporal generalization relies on long-term memory as well as timing processes (McCormack et al., 2002). This is because, with the latter task, participants are presented with a reference duration during a preexposure phase and are required to judge whether the durations presented during the test phase are the same as the reference duration that they have encountered earlier.

1.4.1. Stimuli

The stimuli were sine wave tones presented through headphones at an intensity of 67 dB SPL. In the range of seconds, the standard stimulus duration was 1000 ms and the nonstandard durations were 700, 800, 900, 1100, 1200, and 1300 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.

1.4.2. Procedure

Performance on temporal generalization was assessed separately for intervals in the range of milliseconds and seconds. Order of the two temporal generalization tasks was randomized and balanced across participants. Participants were required to identify the standard stimulus among the six nonstandard stimuli. In the first part of the experiment, participants were instructed to memorize the standard stimulus duration. For this purpose, the standard interval was presented five times accompanied by the display "This is the standard duration". Then participants were asked to start the test. The test task consisted of eight blocks. Within each block, the standard duration was presented twice, while each of the six nonstandard intervals were presented once. All duration stimuli were presented in randomized order.

On each test trial, one duration stimulus was presented. Participants were instructed to decide whether or not the presented stimulus was of the same duration as the standard stimulus stored in memory. Immediately after presentation of a stimulus, the display "Was this the standard duration?" appeared on the screen, requesting the participant to respond by pressing one of two designated response keys. Each response was followed by a visual feedback. As a quantitative measure of performance on temporal generalization, an individual index of response dispersion (McCormack et al., 2002) was determined. For this purpose, the proportion of total "yes" responses to the standard duration and the two nonstandard durations immediately adjacent (e.g., 900, 1000, and 1100 ms) was determined. This measure would approach 1.0 if all "yes" responses were clustered closely around the standard duration.

Although many recent studies of human timing have used temporal generalization tasks, to our knowledge, the reliability of this type of task has not been evaluated yet.

1.5. Rhythm perception task

1.5.1. Stimuli

The stimuli consisted of 3-ms clicks presented binaurally through headphones at an intensity of 88 dB.

1.5.2. Procedure

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 ms+x). The magnitude of x changed from trial to trial depending on the participant's previous response according to the weighted up–down procedure (Kaernbach, 1991) which converged on a probability of hits of 0.75. Correct responding resulted in a decrease of x and incorrect responses made the task easier by increasing the value of x. Thus, the weighted up–down procedure was used to determine the 75% threshold as an indicator of performance on rhythm perception. A total of 64 experimental trials were grouped in two independent series of 32 trials each. In series 1, the third beat-to-beat interval was the deviant interval, while in series 2 the fourth beat-to-beat interval was the deviant interval. Trials from both series were randomly interleaved.

The participant's task was to decide whether the presented rhythmic pattern was perceived as "regular" (i.e., all beat-to-beat intervals appeared to be of the same duration) or "irregular" (i.e., one beat-to-beat interval was perceived as deviant). Participants indicated their decision by pressing one of two designated response keys. No feedback was given, as there were no perfectly isochronous ("regular") patterns presented. In a previous study (Brandler & Rammsayer, 2000), a test–retest reliability coefficient of r_{tt}=0.87 was obtained for the rhythm perception task.

1.6. Temporal-order judgment task

1.6.1. Stimuli

For the TOJ task, visual as well as auditory stimuli were employed. Visual stimuli were generated by a red light-emitting diode (LED) in a black viewer box. The LED was located at about 1 m in front of the participant, subtending a visual angle of 0.58 degree. Auditory stimuli were 1000-Hz square waves presented binaurally via headphones at an intensity of 67 dB.

1.6.2. Procedure

The TOJ 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. Trials from both series were presented randomly. Within each series, duration of SOA varied from trial to trial depending on the participant's previous response according to the weighted up–down procedure (Kaernbach, 1991) which converged on a level of 75% correct responses. 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 and to indicate their decision by pressing one of two designated response keys. As an indicator of TOJ performance, DL was determined. In a pilot study with 12 participants, a test–retest reliability coefficient of r_{tt}=0.73 was obtained for the TOJ task.

1.7. Auditory flutter fusion (AFF) task

1.7.1. Stimuli

The stimuli consisted of 25-ms noise bursts presented binaurally through headphones at an intensity of 88 dB.

1.7.2. Procedure

AFF threshold estimation consisted of 12 trials, and each trial consisted of two noise bursts separated by a variable ISI ranging from 1 to 40 ms. After each trial, the participant's task was to indicate by pressing one of two designated response keys whether he or she perceived the two successive noise bursts as one tone or two separate tones. The ISI was changed using an adaptive rule based on the Best PEST procedure (Pentland, 1980) to estimate the 75% fusion threshold. To enhance reliability of measurement, two AFF-threshold estimates

Table 2
Concise summary of the temporal tasks applied

Acronym	Name of the task	Task description
DD1	Duration discrimination of filled auditory intervals, base duration = 50 ms	Comparison of two consecutively presented filled intervals
DD2	Duration discrimination of auditorily marked empty intervals, base duration = 50 ms	Comparison of two consecutively presented empty intervals
DD3	Duration discrimination of filled auditory intervals, base duration = 1000 ms	Comparison of two consecutively presented filled intervals
TG1	Temporal generalization, base duration = 75 ms	Identification of a previously presented standard interval in a series of comparison intervals shorter than, longer than, or equal to the standard interval
TG2	Temporal generalization, base duration = 1000 ms	
RP	Rhythm perception	Identification of regular and irregular rhythmic patterns
TOJ	Temporal-order judgment	To decide whether the onset of a tone or a light occurred first
AFF	Auditory flutter fusion	To decide whether two successive noise bursts were perceived

were obtained for each participant. Thus, final individual threshold values represented the mean across both measurements. In a pilot study with 55 participants, a test–retest reliability coefficient of $r = 0.87$ was obtained for the AFF task.

A concise summary of the names, acronyms, and a thumbnail description of each temporal task is given in Table 2.

1.8. Modified Hick reaction time paradigm

Since the traditional procedure for the Hick paradigm has been criticized by several authors (e.g., Bors, MacLeod, & Forrin, 1993; Longstreth, 1984, 1986; Widaman & Carlson, 1989), a modified Hick RT paradigm was used similar to the one proposed by Neubauer, Bauer, and Höller (1992).

1.8.1. Stimuli

Stimuli were rectangles (2 cm × 1 cm) and plus signs (0.8 cm) presented on a monitor screen. For registration of the participant's responses, an external response panel with four buttons corresponding to the locations of the four rectangles presented under the 2-bit condition (see Fig. 1) was connected to the computer. Responses were recorded with an accuracy of ±1 ms.

1.8.2. Procedure

In the 0-bit condition (no-choice or simple RT), one rectangle was presented in the center of the screen (see Fig. 1). After a foreperiod varying randomly between 700 and 2000 ms, the imperative stimulus, a plus sign, was presented in the center of the rectangle. The rectangle and the plus sign remained on screen until the participant pressed a designated response button.

The 1-bit condition (two-choice RT) was almost identical to the 0-bit condition, except that two rectangles were presented arranged in a row. After a variable foreperiod, the imperative stimulus was presented in one of the two rectangles. Presentation of the imperative stimulus was randomized and balanced. Thus, the imperative stimulus appeared in each of the two rectangles in 50% of the trials.

Similarly, in the 2-bit condition (four-choice RT), four rectangles arranged in two rows were displayed on the monitor screen. Again, the imperative stimulus was presented randomly in one of the four rectangles after a variable foreperiod. The instruction to the participants emphasized to respond as quickly as possible to the imperative stimulus by pressing the response button corresponding to the rectangle with the imperative stimulus.

After each correct response, a 200-ms tone was presented immediately after pressing the response button followed by an intertrial interval of 1500 ms. To avoid order effects, the order of conditions was randomized across participants. Each condition consisted of 32 trials preceded by 10 practice trials.

As indicators of individual performance, median RT and intraindividual variability (standard deviation) were computed separately for the 0-, 1-, and 2-bit conditions. In addition, intercept and slope of the regression line over RT medians per bit level were determined for each participant.

1.9. Time course of the study

The intelligence tests and experimental tasks were implemented in two testing sessions of 90 min each. The

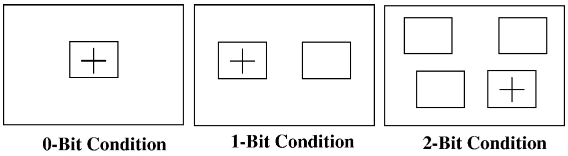

Fig. 1. Stimulus presentation with the modified Hick paradigm.

Table 3
Descriptive statistics (mean, SEM, min, max) of all performance measures obtained

Performance measure	Mean	S.E.M.	Min	Max
Intelligence tests				
Verbal comprehension	25.7	0.67	6	37
Word fluency	31.0	0.83	8	40
Space 1	22.6	0.72	6	40
Space 2	28.8	0.68	7	40
Closure	31.7	0.73	4	40
Perceptual speed	26.5	0.48	13	38
Series	6.7	0.26	0	12
Classifications	6.5	0.22	1	11
Matrices	5.9	0.24	0	10
Topologies	5.5	0.17	1	8
Number 1	23.6	0.70	6	41
Number 2	4.1	0.20	0	7
Verbal memory	8.8	0.26	3	18
Numerical memory	7.3	0.25	1	14
Spatial memory	14.8	0.49	4	27
Temporal tasks				
DD1	9.0	0.35	3.3	24.2
DD2	17.5	0.79	4.1	43.6
DD3	131.9	5.4	56	356
TG1	.78	0.01	0.49	1.00
TG2	.75	0.02	0.43	1.00
RP	52.5	1.6	11.4	99.2
TOJ	83.6	2.8	22.9	149.2
AFF	7.0	0.51	2	22
Hick parameters				
RT 0-bit	248	2.8	200	338
RT 1-bit	307	3.6	243	485
RT 2-bit	387	5.9	269	670
SD 0-bit	63	3.3	21	201
SD 1-bit	58	2.8	23	221
SD 2-bit	72	3.1	36	298
Intercept	261	2.9	207	338
Slope	66	2.6	25	220

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 = 1000 ms; TG1 temporal generalization, base duration = 75 ms; TG2 temporal generalization, base duration = 1000 ms; RP rhythm perception; TOJ temporal-order judgment; AFF auditory flutter fusion; RT reaction time; SD intraindividual standard deviation.

order of testing sessions was counterbalanced across participants. For half of the participants, the experimental tasks were preceded by psychometric assessment of intelligence, while for the other half intelligence tests were administered after the experimental tasks. Both testing sessions were separated by a 1-week interval.

All experiments were carried out in a sound-attenuated room. The experimental session was initiated by the three duration discrimination tasks followed by TOJ, rhythm perception, the two temporal generalization tasks, the AFF task, and the RT task based on the Hick paradigm. Order of the three duration discrimination tasks was balanced across participants. 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.

2. Results

Table 3 reports means, standard errors of the mean, as well as minimum and maximum of the observed values of all performance measures obtained in the present study. In order to obtain an estimate of psychometric *g*, all psychometric test scores were subjected to a principal components analysis (PCA). The scree criterion was applied to the extraction of factors (Cattell, 1966; Cattell & Vogelmann, 1977). Based on the scree test, PCA yielded only one factor with an eigenvalue of 5.72 that accounted for 38% of total variance. This first unrotated component is commonly considered an estimate of psychometric *g* (Jensen, 1998a). As can be seen from Table 4 (columns 1 and 2), all mental tests exhibited substantial positive loadings greater than 0.30 on this factor. Apart from the three memory scales, all loadings were greater than 0.50.

For assessment of the relationship between psychometric *g* and performance on the eight different temporal tasks and the measures derived from the Hick paradigm, a correlational approach was applied. It is important to note that the index of response dispersion obtained with the temporal generalization tasks is positively related to performance, i.e., better performance is indicated by higher values of response dispersion, while the other psychophysical measures based on threshold estimates are negatively associated with temporal performance, i.e., better performance is reflected by lower threshold values and DLs. To enhance the clarity of data presentation, the sign (+ or −) of the correlation coefficients presented in Tables 4, 5, and 7 has been adjusted in a way that positive correlation coefficients indicate a positive covariation of performance for all temporal tasks. A complete unadjusted correlation matrix for all measures obtained is given in Appendix A.

Correlational analyses yielded statistically significant positive correlations between individual factor scores on psychometric *g* and performance on all temporal tasks except AFF (see Table 5). This positive relationship indicates that a higher level of psychometric *g* is associated with better temporal accuracy. As can also be seen from Table 5, most of the Hick parameters displayed moderate, albeit significant, negative correlations with

Table 4
Factor analytic results obtained from PCA: factor loadings of intelligence scales, temporal tasks, and Hick parameters on respective first unrotated components (psychometric *g*, temporal *g*, and Hick *g*), eigenvalues, and percentage of explained variance

Intelligence scale	Psychometric *g*	Temporal task	Temporal *g*	Hick parameter	Hick *g*
Verbal comprehension	0.70	DD1	0.68	RT 0-bit	0.66
Word fluency	0.70	DD2	0.74	RT 1-bit	0.89
Space 1	0.53	DD3	0.75	RT 2-bit	0.87
Space 2	0.74	TG1	0.65	SD 0-bit	0.27
Closure	0.69	TG2	0.72	SD 1-bit	0.60
Perceptual speed	0.54	RP	0.45	SD 2-bit	0.56
Series	0.58	TOJ	0.68	Intercept	0.70
Classifications	0.66	AFF	0.27	Slope	0.65
Matrices	0.69				
Topologies	0.73				
Number 1	0.58				
Number 2	0.73				
Verbal memory	0.31				
Numerical memory	0.36				
Spatial memory	0.50				
Eigenvalue	5.72	Eigenvalue	3.25	Eigenvalue	3.64
Explained variance (%)	38.12	Explained variance (%)	40.59	Explained variance (%)	45.52

psychometric *g* as predicted by the speed of information processing approach to intelligence.

As a second step for further assessment of the relationship between psychometric *g* and the experimental tasks, stepwise multiple regression analyses were performed taking into consideration those indicators of performance that were substantially correlated with psychometric *g*. As a single variable, duration discrimination of empty intervals in the range of milliseconds was the most powerful predictor accounting for 19% of total variance of overall variability in psychometric *g* (R^2; see Table 6). When combining two predictor variables, duration discrimination of empty intervals and the slope parameter derived from the Hick task represented the best combination of predictors explaining 26% of total variance. This combined effect yielded a statistically significant increase of 7% (ΔR^2) in explained variance as compared to the portion of 19% accounted for by duration discrimination of empty intervals in the range of milliseconds alone [$F(1,97)=9.29$, $p=0.003$]. Adding duration discrimination of filled intervals in the range of seconds to the latter two predictor variables resulted in an additional reliable increase in explained variance of 4% [$F(1,96)=6.05$, $p=0.015$]. Inclusion of any further predictor variable failed to provide another substantial increase in explained variance.

As can be seen from Table 7, most measures of temporal performance were significantly correlated with each other. Only rhythm perception and AFF exhibited lower and mainly nonsignificant correlations with other aspects of temporal performance. Scattergram analyses revealed that the observed significant correlations were not due to outliers. Thus, the pattern of results can be described as a positive manifold (cf. Carroll, 1993). The observed positive manifold as well as inspection of the anti-image matrix and Kaiser's (1974) measure of sampling adequacy indicated that the correlation matrix was legitimately factorable. Therefore, to further analyze the dimensional structure of the eight temporal tasks, a PCA was performed. A scree test indicated a one-factor solution that accounted for 40% of total temporal variance (see Table 4, columns 3 and 4). Duration discrimination, temporal generalization, and TOJ tasks loaded highest on this factor referred to as "temporal *g*", while AFF showed no substantial loading.

Table 5
Correlations between factor scores on psychometric *g* and performance on temporal tasks and Hick parameters, respectively

Temporal task	Psychometric *g*	Hick parameter	Psychometric *g*
DD1	0.39***	RT 0-bit	−0.07
DD2	0.43***	RT 1-bit	−0.29**
DD3	0.43***	RT 2-bit	−0.32***
TG1	0.37***	SD 0-bit	−0.18
TG2	0.35***	SD 1-bit	−0.27**
RP	0.34***	SD 2-bit	−0.33***
TOJ	0.36***	Intercept	−0.15
AFF	0.17	Slope	−0.28**
Temporal *g*	0.56***	Hick *g*	−0.34***

**$p<0.01$, ***$p<0.001$ (two-tailed).

Table 6
Results of stepwise regression analyses

Predictor variable(s)	R	R^2	F value	p value	ΔR^2	F value	p value
DD2	0.43	0.19	22.33	0.001			
DD2+Slope	0.51	0.26	16.75	0.001	0.07	9.29	0.003
DD2+Slope+DD3	0.55	0.30	13.76	0.001	0.04	6.05	0.015

Since correlational analyses also suggested a positive manifold among performance measures derived from the Hick task (see Table 8), Hick parameters were also subjected to a PCA. Again, the scree test indicated a one-factor solution that accounted for a portion of 45% of total variability in Hick parameters (see Table 4, columns 5 and 6). Except for intraindividual variability under the 0-bit condition, all Hick parameters exhibited substantial positive loadings ranging from 0.56 to 0.89 on the first unrotated component referred to as “Hick *g*”.

In a final step, correlational and commonality analyses were performed on the compound measures psychometric *g*, temporal *g*, and Hick *g*. A correlation coefficient of 0.56 ($p<0.001$) indicated a substantial positive linear relationship for individual factor scores on psychometric *g* and temporal *g*. The correlation between factor scores on psychometric *g* and Hick *g* was −0.34 ($p<0.001$). This negative relationship is the predicted direction given that smaller values represent better performance on the Hick task. Since in the present study, participants ranged from 18 to 45 years of age and the measures adopted were not age-normed, the possibility is that the observed correlational relationships among psychometric *g*, temporal *g*, and Hick *g* were compromised by this age disparity. Therefore, additional correlations controlling for age were computed resulting in correlation coefficients of 0.56 and 0.33 for psychometric *g* and temporal *g*, and psychometric *g* and Hick *g*, respectively. Thus, partial correlations with age held constant were virtually identical to the correlation coefficients not controlled for age.

Stepwise multiple regression analysis showed that temporal *g* and Hick *g* accounted for statistically significant portions of 31% and 12%, respectively, of the total variance of overall variability in psychometric *g*. Combining temporal *g* and Hick *g* accounted for 33% of total variance. This combined effect did not represent a significant increase in explained variance as compared to the portion of 31% accounted for by temporal *g* alone [$F(1,97)=2.39$, $p>0.10$]. As stepwise multiple regression analysis does not allow to determine the unique and the confounded contribution of several predictor variables to the explanation of the variance of the criterion variable, additional commonality analyses (Cooley & Lohnes, 1976; Kerlinger & Pedhazur, 1973) were performed. In multivariate prediction of a single criterion measure by two predictors, commonality analysis partitions the criterion variance into the unique contribution of each predictor and the confounded contribution of both predictors combined, referred to as commonality (Cooley & Lohnes, 1976). With regard to the prediction of psychometric *g*, commonality analysis revealed that the confounded contribution of both, temporal *g* and Hick *g*, was 10.5% of explained variance in psychometric *g*. The unique contribution of Hick *g* to the prediction of psychometric *g* was 1.5%, whereas temporal *g* contributed 20.5% of unique variance.

3. Discussion

In the present study, we put forward Surwillo’s (1968) notion of an internal master clock responsible for coordination of various neural activities. According to this account, higher clock rate should not only enable an individual to perform a specific sequence of mental operations faster, but should also decrease the probability of occurrence of interfering incidents. This should result in superior performance in tests of psychometric intelligence as well as in basic information processing skills. Within the framework of traditional mental-speed

Table 7
Intercorrelations among temporal performance measures

	DD1	DD2	DD3	TG1	TG2	RP	TOJ
DD2	0.46***						
DD3	0.54***	0.52***					
TG1	0.38***	0.41***	0.32***				
TG2	0.34***	0.43***	0.46***	0.55***			
RP	0.19	0.30**	0.30**	0.14	0.17		
TOJ	0.37***	0.47***	0.45***	0.30**	0.36***	0.28**	
AFF	−0.03	0.17	0.03	0.15	0.27**	0.22*	0.19

*$p<0.05$, **$p<0.01$, ***$p<0.001$ (two-tailed).

Table 8
Intercorrelations among Hick parameters

	RT 0-bit	RT 1-bit	RT 2-bit	SD 0-bit	SD 1-bit	SD 2-bit	Intercept
RT 1-bit	0.62***						
RT 2-bit	0.49***	0.75***					
SD 0-bit	0.03	0.17	0.11				
SD 1-bit	0.12	0.43***	0.38***	0.21*			
SD 2-bit	0.15	0.28**	0.39***	0.19	0.52***		
Intercept	0.83***	0.69***	0.40***	0.27**	0.28**	0.20*	
Slope	0.05	0.52***	0.84***	0.02	0.38***	0.44***	−0.02

*$p<0.05$, **$p<0.01$, ***$p<0.001$ (two-tailed).

approaches to intelligence, RT measures have been commonly used to attain an index of performance on information processing. As an alternative, and potentially more direct measure of internal clock speed that may be stronger related to individual levels of psychometric *g*, three duration discrimination tasks, two temporal generalization tasks, rhythm perception, TOJ, and AFF were evaluated in the present study.

As a measure of psychometric *g*, the first unrotated principle component extracted from 14 different intelligence scales was used. Correlational analyses revealed a reliable linear relationship between individual factor scores on psychometric *g* and all temporal tasks with correlation coefficients ranging from 0.34 to 0.43, except for AFF. Thus, at this point, it seems that temporal acuity, as obtained with seven different temporal tasks, is somehow related to psychometric *g*.

With a correlation coefficient of 0.17, AFF threshold failed to reliably predict psychometric *g*. A similar result was reported by Rammsayer and Brandler (2002) who obtained a negligible correlation of −0.04 between AFF threshold values and individual CFT scores as an indicator of general fluid intelligence. Also Jensen (1983) did not find a significant correlational relationship between visual critical flicker fusion frequency and psychometric intelligence. Taken together, these findings suggest that there is no functional relationship between psychometric *g* and temporal resolving power for central sensory information processing as indicated by fusion thresholds irrespective of the sensory modality involved.

If temporal acuity represents a more valid measure of brain processes associated with psychometric *g* than traditional mental speed approaches such as the Hick paradigm, then the portion of explained variance of psychometric *g* should be substantially larger for temporal performance measures than for the parameters derived from the Hick paradigm. Therefore, correlations between individual factor scores of psychometric *g* and performance on the eight temporal tasks were contrasted with correlations between psychometric *g* and parameters derived from the Hick paradigm. On the whole, the number of reliable correlations and the size of the relationship appeared to be somewhat higher for the temporal tasks compared to the Hick parameters.

When comparing the obtained coefficients relating psychometric *g* to performance on the Hick task with the ones reported in the literature (e.g., Detterman, 1987; Jensen, 1987; Neubauer et al., 1997), it becomes obvious that the present findings conform quite well with previous studies in this field. There were only two noticeable exceptions from the majority of previous studies. First, with a correlation coefficient of −0.07, RT under the 0-bit condition was virtually unrelated to psychometric *g*. Although, as a general rule, an increase in the number of bits of information is associated with increasing correlation coefficients between RT and mental *g* (Eysenck & Eysenck, 1985; Lally & Nettlebeck, 1977), it remains unclear whether this could account for the lack of a correlational relationship observed for the 0-bit RT task.

A second rather unexpected finding represented the relatively high correlation between the slope *b* and psychometric *g*. Theoretically, the slope of the regression line relating bits of information to RT should provide a valid indicator of the rate of information processing and, therefore, should be more highly correlated with psychometric *g* than any other Hick parameter (Jensen, 1982, 1987; Jensen and Munro, 1979; Roth, 1964). Data obtained with the traditional Hick task, however, indicated that slope measures are not as strongly related to psychometric *g* as measures of speed and variability of RT (e.g., Barrett, Eysenck, & Lucking, 1986; Jensen, 1987; Beauducel & Brocke, 1993; Carlson, Jensen, & Widaman, 1983). This typically found low correlation between slope and psychometric *g* apparently contradicts the notion that rate of information processing is a component of psychometric *g*. Tentative explanations for this finding referred to a lack of stability of this parameter (Jensen, 1987) as well as to statistical artifacts that suppress higher correlations with the slope *b* (Jensen, 1998b). The modified Hick task, first introduced by Neubauer (1991) and Neubauer et al. (1997) and also applied in the present study, seems to have overcome this weakness of the traditional Hick task and can be considered a more sensitive task with regard to the slope parameter. Uncorrected correlations between slope and psychometric *g* were −0.24 and −0.28 in the Neubauer et al. (1997) study and in the present study, respectively. This newly observed major contribution of the slope parameter to account for psychometric *g* is consistent with the idea put forward by Roth (1964) that in less intelligent individuals RTs increase more rapidly with increase of bits of information than do RTs in highly intelligent individuals.

In order to identify the most powerful variables for the prediction of psychometric *g*, all temporal tasks and Hick parameters obtained in the present study were subjected to stepwise multiple regression analyses. As the most powerful single predictor variable, duration discrimination of brief empty intervals in the range of milliseconds (DD2) accounted for 19% of total variance in variability of psychometric *g*. This finding clearly corresponded with the outcome of Rammsayer and Brandler's (2002) study where, as the strongest predictor variable, DD2 explained a portion of 18.5% of variance of psychometric *g*.

When combining two variables, DD2 and the slope parameter of the Hick task explained the largest portion of total variance (26%). The combination of DD2, slope *b*, and duration discrimination of filled intervals in the range of seconds (DD3) resulted in another significant increase in explained variance of 4%. Thus, these three variables together predicted 30% of overall variability in psychometric *g*. Inclusion of any further predictor variable did not result in a statistically significant increase in explained variance. This outcome of the stepwise regression analysis is consistent with the view that both psychometric *g* and interval timing performance draw on some common general properties of the central nervous system. Furthermore, the reliable contribution of the slope parameter indicates that RT as a function of bits of information, rather than just speed or variability of RT, provides an additional aspect of neural functioning that is related to psychometric *g* but not accounted for by any of the specific temporal tasks.

Inspection of the intercorrelation matrices showed that most performance measures were significantly correlated with each other. This was true for both the temporal tasks (see Table 7) and the Hick parameters (see Table 8). Both these patterns could be described as a positive manifold (Carroll, 1993). Since all the intercorrelations among different tasks represent a general factor influencing each task to a different degree (Eysenck & Eysenck, 1985), PCAs were performed on both sets of variables to track down the assumed unitary dimensions reflected by the positive manifolds observed with the temporal tasks and the Hick parameters, respectively. For the temporal tasks and the Hick parameters, one-factor solutions accounted for 40% and 45% of total temporal variance and variability in Hick parameters, respectively. With regard to the temporal tasks, this finding is consistent with the notion of a unitary internal clock mechanism involved in temporal information processing. The low factor loading of the AFF task on temporal *g* indicated that AFF thresholds may differ qualitatively from the other seven temporal tasks as recently proposed by Rammsayer and Brandler (2004). This qualitative difference may also account for the above-mentioned conclusion based on the correlational data that there is no functional relationship between psychometric *g* and temporal resolving power for central sensory information processing as indicated by fusion thresholds.

The high correlation of .56 between psychometric *g* and temporal *g* points to a strong functional relationship between both aspects of information processing. Thus, temporal *g* represents a much more powerful predictor than each of the particular temporal tasks. Although the correlational relationship between factor scores on psychometric *g* and Hick *g* was markedly less pronounced (−0.34), it was slightly stronger than the one between psychometric *g* and the most powerful single predictor derived from the Hick paradigm. Eysenck and Eysenck (1985) argued that higher correlations between intelligence and parameters derived from the Hick paradigm could be obtained if RT, intraindividual variability, and slope of the regression line were combined to a compound measure. Hick *g*, the first unrotated principal component, extracted from the eight different Hick parameters obtained in the present study, clearly represented such a compound measure.

Temporal *g* predicted 31% of variability in psychometric *g*, while combining temporal *g* and Hick *g* as two predictors resulted in 33% explained variance. This marginal increase in explained variance of only 2% indicated that an essential portion of the shared variance of psychometric *g* and Hick *g* is already accounted for by temporal *g*. Furthermore, commonality analyses revealed that this finding can be attributed to the fact that the portion of intellectual variance explained by the Hick paradigm predominantly represented variance components also explained by temporal acuity. In contrast to Hick *g* which did not provide a substantial unique contribution to the explanation of variance in psychometric *g* (1.5%), temporal *g* contributed a considerable portion of unique variance of 20.5% to the prediction of. psychometric *g*. Thus, temporal *g* traps an aspect of brain functioning that is stronger and more comprehensively related to psychometric *g* than Hick *g*. As explicitly stated by Jensen (1998a), a cautionary note is that psychometric *g* "is *not* a mental or cognitive process or one of the operating principles of the mind, such as perception, learning, or memory.... Rather, *g* only reflects some part of the *individual differences* in mental abilities...that undoubtedly depend on the operation of neural processes in the brain. By inference, *g* also reflects individual differences in the speed, or efficiency, or capacity of these operations. But *g* is not theses operations themselves" (p. 95). From this perspective, factors such as psychometric *g*, temporal *g*, or Hick *g* just demonstrate the existence of a respective single dimension of individual differences that cuts across a set of performance tasks. Hence, the observed portion of shared variance between psychometric *g* and temporal *g* reflects a latent variable accounting for individual differences in both psychometric intelligence and temporal information processing, respectively.

Since the intelligence scales employed in the present study to obtain a *g* factor were administered under strict time-limited conditions, it remains unclear to what extent our results may be influenced by this fact. In a most recent study, we examined the relationship between timing performance and psychometric intelligence as measured by a time-limited speed test and an untimed power test (Helmbold & Rammsayer, 2006). Our findings indicate a slightly stronger correlational relationship between temporal processing and the untimed power test than between temporal processing and the time-limited speed test. Thus, the present findings do not appear to be restricted to time-limited conditions.

Obviously, variation in levels of psychometric *g* is linked to aspects of information processing capacity. To date, however, little is known about the basic biological mechanisms by which this is achieved (cf. Hunt, 1999; Jensen, 1998a; Sternberg & Kaufman, 1998). Proceeding from the general assumption that psychometric *g* is a function of the central nervous system to process information quickly and correctly, different biological phenomena have been introduced as prime candidates for a biological basis of psychometric *g*: neuronal refractory periods (Jensen, 1982), reliability of neuronal transmission (Hendrickson & Hendrickson, 1980), neural pruning (Haier, 1993), myelination of neurons (Miller, 1994), or differences in neural plasticity (Garlick, 2002). On the whole, all these accounts refer to neural efficiency in the brain as a basic determinant of individual differences in psychometric *g* (Bates, Stough, Mangan, & Pellett, 1995; Sternberg & Kaufman, 1998).

These biological approaches can be easily translated into metaphors related to information processing. For example, Jensen (1982) suggested an oscillation rate of neurons underlying individual differences in speed and efficiency of information processing to account for the observed negative relationship between psychometric *g* and performance measures derived from the Hick paradigm. According to his view, the brain acts as a limited-capacity information-processing system which can deal simultaneously with only a very limited amount of information. Furthermore, limited capacity also restricts the number of mental operations that can be executed per unit of time.

In the present study, Surwillow's (1968) concept of a hypothetical master clock has been introduced as an alternative metaphor based on aspects of information processing. The master clock view predicts higher levels of psychometric *g* to be associated with a faster clock rate or finer temporal resolution power of the central nervous system. Furthermore, the master clock hypothesis suggests that temporal tasks rather than RT measures as derived from the Hick paradigm provide more direct and, thus, more valid predictors of psychometric *g*. The present findings supported these predictions; especially by demonstrating that predicting power of temporal *g* was substantially higher than the predicting power of Hick *g*. Besides this, Hick *g* failed to make a significant contribution to account for total variance of psychometric *g* on top of the portion explained by temporal *g*.

In conclusion, temporal information processing and interval timing represent simple information processing tasks that are clearly related to psychometric *g*. Future studies will have to show whether temporal tasks can provide more insight than RT measures into the fundamental mechanisms that account for individual differences in psychometric *g*.

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Appendix A

Complete correlation matrix for all 31 measures obtained. Decimal points omitted

		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Verbal comprehension	71	29	47	53	38	26	31	33	32	44	44	39	27	27	−23
2	Word fluency		28	49	45	49	20	37	33	32	38	50	31	16	29	−20
3	Space 1	28		35	34	29	23	27	28	44	36	39	05	02	19	−13
4	Space 2	49	35		53	31	32	42	50	54	33	51	32	18	37	−45
5	Closure	45	34	53		42	33	32	35	50	29	44	24	21	31	−26
6	Perceptual speed	49	29	31	42		19	14	26	24	45	43	18	02	13	−15
7	Series	20	23	32	33	19		49	72	50	22	30	−04	17	34	−25
8	Classifications	37	27	42	32	14	49		58	51	35	47	08	31	43	−29
9	Matrices	33	28	50	35	26	72	58		53	27	39	06	24	28	−20
10	Topologies	32	44	54	50	24	50	51	53		31	54	09	26	33	−28
11	Number 1	38	36	33	29	45	22	35	27	31		53	04	14	10	−25
12	Number 2	50	39	51	44	43	30	47	39	54	53		12	24	24	−31
13	Verbal memory	31	05	32	24	18	−04	08	06	09	04	12		26	25	−03
14	Numerical memory	16	02	18	21	02	17	31	24	26	14	24	26		21	−28
15	Spatial memory	29	19	37	31	13	34	43	28	33	10	24	25	21		−20
16	DD1	−20	−13	−45	−26	−15	−25	−29	−20	−28	−25	−31	−03	−28	−20	
17	DD2	−24	−26	−38	−28	−15	−15	−32	−18	−35	−33	−45	−03	−07	−27	46
18	DD3	−32	−22	−41	−32	−24	−21	−25	−18	−32	−24	−36	−17	−19	−16	54
19	TG1	19	28	40	21	13	16	26	29	25	20	28	08	08	26	−38
20	TG2	28	17	33	24	07	03	25	19	25	21	26	12	12	23	−34
21	RP	−25	−12	−28	−27	−15	−14	−26	−16	−37	−25	−36	05	−19	−14	19
22	TOJ	−20	−26	−28	−30	−26	−12	−10	−07	−31	−46	−38	−06	−09	−06	37
23	AFF	−14	−13	−23	−08	−16	02	−01	01	−13	−28	−16	−07	07	−11	−03
24	RT 0-bit	−16	−10	−01	02	−14	05	−05	14	06	−17	−10	−01	07	−16	23
25	RT 1-bit	−30	−26	−23	−11	−13	−07	−16	−03	−13	−29	−29	−11	−15	−24	28
26	RT 2-bit	−21	−34	−21	−14	−16	−13	−25	−11	−24	−31	−32	−08	−13	−24	26
27	SD 0-bit	−17	−08	−08	−13	−19	−10	−09	−18	−05	−22	−10	05	−08	02	13
28	SD 1-bit	−14	−29	−20	−11	−07	−16	−20	−18	−21	−18	−17	−06	−11	−27	21
29	SD 2-bit	−27	−15	−32	−25	−15	−20	−22	−15	−22	−17	−25	00	−09	−14	34
30	Intercept	−20	−05	−06	−02	−15	02	−10	11	02	−25	−16	−07	−05	−22	22
31	Slope	−18	−31	−23	−16	−05	−11	−21	−16	−23	−23	−27	−06	−14	−18	18

		17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	Verbal comprehension	−24	−37	26	35	−13	−22	−10	−11	−16	−08	−23	−15	−31	−21	−02
2	Word fluency	−24	−32	19	28	−25	−20	−14	−16	−30	−21	−17	−14	−27	−20	−18
3	Space 1	−26	−22	28	17	−12	−26	−13	−10	−26	−34	−08	−29	−15	−05	−31
4	Space 2	−38	−41	40	33	−28	−28	−23	−01	−23	−21	−08	−20	−32	−06	−23
5	Closure	−28	−32	21	24	−27	−30	−08	02	−11	−14	−13	−11	−25	−02	−16
6	Perceptual speed	−15	−24	13	07	−15	−26	−16	−14	−13	−16	−19	−07	−15	−15	−05
7	Series	−15	−21	16	03	−14	−12	02	05	−07	−13	−10	−16	−20	02	−11
8	Classifications	−32	−25	26	25	−26	−10	−01	−05	−16	−25	−09	−20	−22	−10	−21
9	Matrices	−18	−18	29	19	−16	−07	01	14	−03	−11	−18	−18	−15	11	−16
10	Topologies	−35	−32	25	25	−37	−31	−13	06	−13	−24	−05	−21	−22	02	−23
11	Number 1	−33	−24	20	21	−25	−46	−28	−17	−29	−31	−22	−18	−17	−25	−23
12	Number 2	−45	−36	28	26	−36	−38	−16	−10	−29	−32	−10	−17	−25	−16	−27
13	Verbal memory	−03	−17	08	12	05	−06	−07	−01	−11	−08	05	−06	00	−07	−06
14	Numerical memory	−07	−19	08	12	−19	−09	07	07	−15	−13	−08	−11	−09	−05	−14
15	Spatial memory	−27	−16	26	23	−14	−06	−11	−16	−24	−24	02	−27	−14	−22	−18
16	DD1	46	54	−38	−34	19	37	−03	23	28	26	13	21	34	22	18
17	DD2		52	−41	−43	30	47	17	22	27	23	18	12	09	24	09
18	DD3	52		−32	−46	30	45	03	18	17	02	17	22	23	28	−07
19	TG1	−41	−32		55	−14	−30	−15	−18	−29	−30	−14	−19	−12	−17	−19
20	TG2	−43	−46	55		−17	−36	−27	−12	−27	−15	−31	−19	−14	−33	−03
21	RP	30	30	−14	−17		28	22	09	17	22	06	01	15	17	21
22	TOJ	47	45	−30	−36	28		19	22	33	32	15	14	17	30	22
23	AFF	17	03	−15	−27	22	19		10	08	06	01	07	09	12	03
24	RT 0-bit	22	18	−18	−12	09	22	10		62	49	03	12	15	83	05

Appendix A (*continued*)

		17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
25	RT 1-bit	27	17	−29	−27	17	33	08	62		75	17	43	28	69	52
26	RT 2-bit	23	02	−30	−15	22	32	06	49	75		11	38	39	40	84
27	SD 0-bit	18	17	−14	−31	06	15	01	03	17	11		21	19	27	02
28	SD 1-bit	12	22	−19	−19	01	14	07	12	43	38	21		52	28	38
29	SD 2-bit	09	23	−12	−14	15	17	09	15	28	39	19	52		20	44
30	Intercept	24	28	−17	−33	17	30	12	83	69	40	27	28	20		−02
31	Slope	09	−07	−19	−03	21	22	03	05	52	84	02	38	44	−02	

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