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Fluid intelligence and executive functioning more alike than different?

Van Aken L, Kessels RPC, Wingbermühle E, Van der Veld WM, Egger JIM. Fluid intelligence and executive functioning more alike than different?

Objective: Fluid intelligence (Gf) has been related to executive functioning (EF) in previous studies, and it is also known to be correlated with crystallized intelligence (Gc). The present study includes representative measures of Gf, Gc, and EF frequently used in clinical practice to examine this Gf–EF relation. It is hypothesised that the Gf–EF relation is higher than the Gc–EF relation, and that working memory in particular (as a measure of EF) shows a high contribution to this relation. **Method:** Confirmatory factor analysis was performed on a mixed neuropsychiatric and non-clinical sample consisting of 188 participants, using the Kaufman Adolescent and Adult Intelligence Test, and three executive tasks of the Cambridge Neuropsychological Test Automated Battery, covering working memory, planning skills, and set shifting. **Results:** The model fitted the data well [$\chi^2(24) = 35.25$, $p = 0.07$, RMSEA = 0.050]. A very high correlation between Gf and EF was found (0.91), with working memory being the most profound indicator. A moderate to high correlation between Gc and EF was present. Current results are consistent with findings of a strong relation between Gf and working memory. **Conclusion:** Gf and EF are highly correlated. Gf dysfunction in neuropsychiatric patients warrants further EF examination and vice versa. It is discussed that results confirm the need to distinguish between specific versus general fluid/executive functioning, the latter being more involved when task complexity and novelty increase. This distinction can provide a more refined differential diagnosis and improve neuropsychiatric treatment indication.

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Significant outcomes

- Fluid deficits warrant further examination of executive functions, and vice versa.
- Fluid intelligence and executive functioning share essential common processes, different from crystallized intelligence. Working memory plays a key role in this relation.
- By investigating separate cognitive constructs, clinicians tend to lose sight of common underlying processes and interaction effects between those constructs. Differentiating between general and specific cognitive deficits is essential in the understanding and explanation of pathological behaviour, and will improve differential diagnosis and neuropsychiatric treatment indication.

Limitations

- Task-complexity plays an important role in the involvement of fluid intelligence; therefore, the inclusion of less multifaceted executive functioning tasks may have resulted in a different outcome.
- A larger data set will allow future multi-group comparisons, using different psychiatric diagnostic groups and healthy controls, and/or different levels of severity in executive dysfunctioning, which could not be done with the current sample.

Introduction

The distinction between fluid (Gf) and crystallized intelligence (Gc), first made by Horn and Cattell (1), has proven to be useful in neuropsychological assessment (2). Gf is the ability to solve novel problems by using reasoning, and Gc is a knowledge-based ability that depends on schooling and acculturation (1,3). Gf and Gc have different functional properties. For instance, fluid abilities tend to decline from the age of 20, whereas Gc stays relatively preserved during ageing. Moreover, Gf is sensitive to brain damage, while Gc typically shows minor impairment after brain lesions (3). Examining general intelligence (*g*), fluid tests consistently appear to be its best predictors (4).

Executive functioning (EF) is a complex concept and beholds multiple cognitive processes which are responsible for controlling and regulating thoughts, emotions, and behaviour and enable us to adjust to new situations (5–7). Miyake et al. (7) identified updating, inhibition, and shifting as separate building blocks of EF, which together are a prerequisite for complex behaviour or 'higher-level executive functions' (5). On the contrary, the unitary nature of EF becomes apparent in, for instance, the supervisory attentional system (SAS) by Norman and Shallice (10). Being a contention scheduling based monitoring programme, SAS selects sets of actions competing for representation and would thus be responsible for executive control of complex, goal-oriented behaviour. In recent years, researchers seemed to agree upon the approach that EF can be conceptualised as a unitary construct as well as consisting of diverse functions (8,9).

Duncan et al. demonstrated that Gf is sensitive to frontal lobe lesions, leading to the conclusion that Gf is in fact a reflection of EF (11). Evidence from functional imaging studies further corroborates this overlap between Gf and EF in patients with frontal lobe lesions (12–14), Parkinson's disease (15), fronto-temporal dementia (16) and schizophrenia (4). In subsequent years, an increasing amount of studies addressed the Gf–EF relation (7–9,17–19). In general, Gf seems to correlate highly with working memory, whereas other aspects of EF (inhibition, mental set-shifting) usually show less strong relations with Gf (7,8,18–23). Recently, Diamond (5) concluded from review of the literature that Gf can be regarded as being completely synonymous to the higher-level executive abilities reasoning and problem-solving.

The Kaufman Adolescent and Adult Intelligence Test (KAIT) is specifically designed to measure Gc and Gf (24). Apart from the Gf–Gc theory (1), Luria's neuropsychological theory of intelligence (25) as well as Piaget's developmental concept of the formal-operational stage (26), gave theoretical direction to the construction of the KAIT (2). Three widely used executive tasks from the Cambridge Neuropsychological Test Automated Battery (CANTAB) will be used to assess EF. The tasks include planning capacity and novel problem solving, working memory, reasoning, mental flexibility, and impulse control (27). Although this is not an exhaustive sample of EF, a wide range of studied EF constructs is included, therefore, the CANTAB tasks representative measures of EF.

Aims of the study

The present study examines the Gf-EF relation using a latent variable approach in a mixed sample of neuropsychiatric patients and non-clinical participants. In addition, it examines the relation of both Gf and EF with Gc. The main hypothesis is that EF, Gf, and Gc are intercorrelated. Based on earlier research in which the Gf–EF relationship has been demonstrated in different (psychiatric) samples, we expect a Gf–EF relation higher than the Gc–EF relation. Furthermore, a high contribution of working memory to this relation can be expected, reflected in higher loadings of those CANTAB tasks on EF that appeal on working memory.

Method

Participants

Included were 188 participants (mean age 39.5 ± 15.5, 51.6% male, $n = 98$). This group consisted of 50 healthy individuals and 138 in- and outpatients of a neuropsychiatric department of a Dutch psychiatric hospital. See Table 1 for demographic variables.

In accordance with the Diagnostic and Statistical Manual for Mental Disorders-Fourth Edition criteria, patients were diagnosed with major affective (including bipolar) disorders (44%), anxiety disorders (17%), impulsivity related psychopathology (9%), psychotic disorders (4%), dementia and other cognitive disorders (4%), developmental disorders (15%) and no formal psychiatric diagnosis (7%),

Table 1. Demographics of the sample population

			Age (years)		Total IQ	
	n	% Male	M	SD	M	SD
Total	188	51.6	39.5	15.5	93.4	17.9
Patients	138	56.5	41.6	15.1	88.0	15.9
Healthy participants	50	38.0	33.5	15.2	111.9	10.8

respectively. Comorbidity with personality disorders was diagnosed in 37% of the patients.

For data analysis, patient identities were concealed. Informed consent was obtained from all healthy volunteers. Participants did not receive any compensation for participation. In accordance with the guidelines of the institutional review board, patient records were drawn from a large electronic database, containing test results of patients admitted in the period from May 2007 to December 2012. The majority of in- and outpatients received medical treatment to relieve symptoms of mental illness.

Materials

KAIT. The KAIT is an intelligence test for individuals between 11 and 85 years and consists of a core battery containing six subtests (three Gf-tasks and three Gc-tasks), from which a composite IQ score can be made up. Test-retest reliabilities are good; 0.80 for Crystallized-IQ, 0.84 for Fluid-IQ and 0.89 for Total-IQ (2,28,29).

The three fluid subtests focus on the integration of modalities and the efficiency of learning (2). *Rebus learning* contains associative learning and visual sequencing and requires intact working memory. *Mystery codes* measures speed of planning. *Logical Steps* beholds syllogistic reasoning and mathematics. The fluid subtests have reliabilities (Cronbach's α) of 0.91, 0.81, and 0.78, respectively (30).

The three crystallized subtests contain the abilities of verbal understanding, verbal expression and verbal-conceptual development. *Definitions* measures the ability to deduct semantic relations, *Auditory comprehension* features auditory sequencing, and *Double meanings* requires semantic flexibility (30). The crystallized subtests have reliabilities (Cronbach's α) of 0.84, 0.84, and 0.81, respectively (30).

CANTAB. The CANTAB is an automated test battery which has proven its utility for empirical research and in clinical practice (31). For further psychometric details on CANTAB tasks and indices, see Lowe and Rabbit (32).

Spatial Working Memory (SWM) is a self-ordered working memory task that also assesses heuristic strategy, measuring the person's ability to retain and manipulate spatial information in the presence of interfering stimuli. Using a process of elimination, tokens have to be found in boxes. The boxes gradually increase in number and the position and colour keep changing per trial, so stereotyped strategies are discouraged. The *number of between errors* (searching tokens in boxes that have been opened before) reflects a person's spatial working memory capacity (33) and is therefore selected for analysis.

The *Stockings of Cambridge (SOC)* is a task of planning and spatial working memory and refers to the ability to organise, plan and execute goal-directed behaviour (6,27). It is a computerised version of the tower tasks. Two displays with both three coloured balls are shown (which look like balls held in stockings). The fixed arrangement of balls in the upper display should be copied by the participant in the lower display. The minimum number of moves to complete the trial is shown on the screen, and increases from two to five moves. The *number of trials completed in the minimum number of moves* is selected as a measure of planning.

Intra-Extra Dimensional Set Shift (IED) is a test of rule acquisition and reversal. It is a computerised analogue of the Wisconsin Card Sorting Test and features maintenance, shifting and flexibility of attention. Two dimensions are used in the test, colour-filled shapes and white lines. Through the process of feedback and rule change, an intradimensional (shapes remain the only relevant dimension) and extradimensional (lines become the only relevant dimension) set shift must be made. When failing to complete one block (six consecutive correct responses) after 50 trials, the test terminates. The *extra dimensional set shift errors* (block 8) are used as a measure of shifting (27). If the task is cancelled before arriving at block 8, participants are given 25 errors on this block, the number of errors made based on chance.

Procedure. KAIT administration (paper-and-pencil) was followed by the CANTAB (computerised). Instructions were given in accordance with the standard administration in the user manuals. Participants were tested individually in a quiet environment. Mean testing time was ~3 h.

Statistical analysis. Using Fisher r-to-z transformation on the sum-scores of Gf, Gc, and EF, group differences between healthy participants and psychiatric patients were tested. Confirmatory factor analysis was performed using LISREL 8.80 (34) on raw data ($n = 188$). Consequently, LISREL uses the *full information maximum likelihood (FIML) estimator*. The FIML procedure in LISREL only produces the FIML χ^2 statistic and the root mean square error of approximation (RMSEA); no other fit indices are provided. A three-factor model was investigated to test the hypothesis that Gf, Gc, and EF are correlated. The factor models were evaluated using both goodness-of-fit measures and standardised factor loadings. As a rule of thumb, RMSEA < 0.05 indicates good fit (35) and standardised factor loadings should be >0.4.

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Results

Descriptive statistics for the nine measures of EF and intelligence are presented in Table 2. Correlations between all measures are shown in Table 3. No group differences in correlations are found for the sum-scores of Gf, Gc, and EF between the psychiatric patients and healthy participants (z-scores all <1.26, p-values all >0.20). Some values of skewness and kurtosis are significant. However, multiple studies have shown that the *maximum likelihood* estimator is robust, under general conditions, against deviations from normality (36–38). Although the IED distribution approaches bimodality, this task is nevertheless included because it is necessary to examine the full scope of EF.

We estimated a three-factor model to test our main hypothesis that Gf, Gc, and EF are correlated. Fig. 1 presents the estimated factor model. All factor loadings were significant ($p < 0.05$) and >0.4. The model fitted the data [$\chi^2(24) = 35.25$, $p = 0.07$, RMSEA = 0.050]. SWM loaded highest on EF, followed by SOC and IED, respectively, meaning this indicator contributed most to EF and to the EF–Gf relation.

It is not possible to directly test the hypothesis that the correlation between EF and Gf is higher than the correlation between EF and Gc. Instead, we tested whether the correlation between EF and Gc is equal to the correlation between EF and Gf. If so, then the hypothesis was rejected. If not, then we looked at the estimated correlations to draw conclusions. The extra constraints on the model were evaluated with the χ^2 difference test. We used the unrestricted three-factor model, as presented in Fig. 1, as the baseline model. The model with equality constraints on the correlations was rejected [$\chi^2(25) = 47.08$, $p = 0.005$, RMSEA = 0.069]. The χ^2 difference

Table 2. Descriptive statistics for the KAIT subtests and CANTAB indices (n = 188)

Task	Range	Mean (SD)	Skewness	Kurtosis
KAIT				
Rebus learning	19–99	69.95 (18.26)	−0.41*	−0.58
Logical steps	0–16	7.81 (4.27)	0.48*	−1.07*
Mystery codes	4–34	18.65 (7.24)	0.14	−0.75*
Definitions	4–27	20.03 (4.20)	−1.22*	1.38*
Auditory comprehension	1–18	9.74 (4.37)	−0.08	−1.09*
Double meanings	0–28	13.59 (5.55)	−0.01	−0.34
CANTAB				
Intra-extra dimensional set shift	0–32	9.04 (10.07)	1.08*	−0.53
Stockings of Cambridge	0–12	8.50 (2.07)	−0.65*	0.97*
Spatial working memory	0–94	28.79 (22.08)	0.60*	−0.33

CANTAB, Cambridge Neuropsychological Test Automated Battery; KAIT, Kaufman Adolescent and Adult Intelligence Test.
*$p < 0.05$.

Table 3. Intercorrelations of the KAIT subtests and CANTAB indices

	KAIT						CANTAB		
	Rebus learning	Logical steps	Mystery codes	Definitions	Auditory comprehension	Double meanings	IED	SOC	SWM
KAIT									
Rebus learning	1								
Logical steps	0.60**	1							
Mystery codes	0.70**	0.71**	1						
Definitions	0.44**	0.40**	0.46**	1					
Auditory comprehension	0.55**	0.58**	0.60**	0.61**	1				
Double meanings	0.49**	0.51**	0.54**	0.63**	0.54**	1			
CANTAB									
IED	−0.25**	−0.29**	−0.31**	−0.15*	−0.26**	−0.26**	1		
SOC	0.42**	0.44**	0.43**	0.32**	0.40**	0.36**	−0.30**	1	
SWM	−0.56**	−0.52**	−0.65**	−0.33**	−0.44**	−0.40**	0.26**	−0.45**	1

CANTAB, Cambridge Neuropsychological Test Automated Battery; IED, Intra-Extra Dimensional Set Shift; KAIT, Kaufman Adolescent and Adult Intelligence Test; SOC, Stocking of Cambridge; SWM, Spatial Working Memory.
*$p < 0.05$; **$p < 0.01$.

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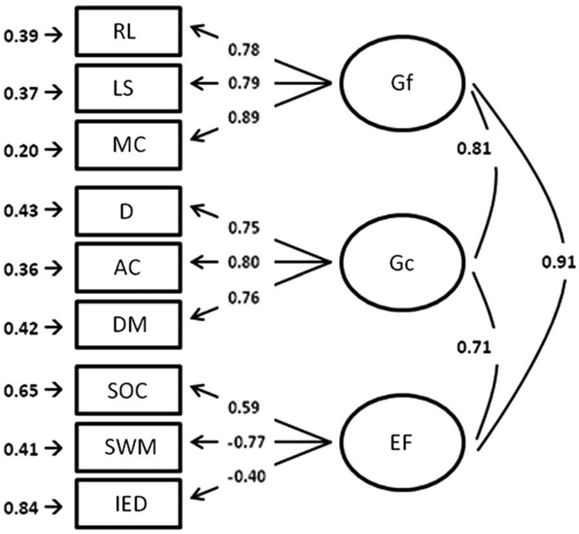

Fig. 1. Structural Equation Modelling examining the relation between Gf and EF. Ellipses represent latent variables, squares represent manifest variables. The curved arrows represent correlations between the latent variables. The straight arrows to the left represent factor loadings, all significant at the .05 level. The small arrows to the right represent residual variances. Residual variances of the latent variables are fixed at 1.00. Negative values are the result of the operationalisation of the manifest variables using error scores. AC, Auditory Comprehension; D, Definitions; DM, Double Meanings; EF, Executive Functioning; Gc, Crystallized Intelligence; Gf, Fluid Intelligence; IED, Intra-Extra Dimensional Set Shift; LS, Logical Steps; MC, Mystery Codes; RL, Rebus Learning; SOC, Stockings of Cambridge; SWM, Spatial Working Memory.

test [$\chi^2(1) = 11.83$] indicated that the extra constraint resulted in a significant increase of χ^2.

Given the high correlation between Gf and EF, similar restrictions were applied to test whether they are interchangeable ($r_{Gf–EF} = 1.00$, $r_{Gc–Gf} = r_{Gc–EF}$). Model fit was moderate [$\chi^2(26) = 39.60$, $p = 0.04$, RMSEA = 0.053], indicating that the two are statistically indistinguishable. We further verified the distinctiveness of this strong EF–Gf relation by comparing them to Gc. Constraints were applied to examine equality between Gf and Gc ($r_{Gf–Gc} = 1.00$, $r_{EF–Gc} = r_{EF–Gf}$) and between all three constructs ($r_{Gf} = r_{Gc} = r_{EF}$). Both restricted models did not fit the data: [$\chi^2(26) = 74.79$, $p = 0.00$, RMSEA = 0.100] and [$\chi^2(26) = 47.11$, $p = 0.01$, RMSEA = 0.066], respectively.

Discussion

The present study examined the relation between EF and Gf in a mixed neuropsychiatric and non-clinical sample using the KAIT as a measure of Gf and Gc, and a selection of CANTAB tasks as a representation of EF. Results showed a significant correlation between Gf and EF, which were statistically indistinguishable in the current model. Working memory was a profound indicator for EF, represented in a high loading of SWM, followed by SOC. Current results are consistent with previous findings of a strong relation between Gf and working memory (8,20–22).

Looking at Table 3, SWM shows higher correlations with the KAIT fluid subtests than the other CANTAB tasks do. Although the fluid subscale of the KAIT is assumed to measure a broad scope of cognitive requirements (associative learning, sequencing, planning, syllogistic reasoning, mathematics, hypothetic-deductive reasoning and flexibility), spatial working memory seems to be an essential requirement for an adequate execution of the tasks. Hence, the structure of the KAIT and CANTAB was the starting point of the developed model. An alternative model with the SWM as predictor of Gf was not tested, since it would not contribute to the understanding of either the KAIT or CANTAB. Still, results strengthen the assumption that working memory plays a key role in understanding Gf (17).

Previously, underlying performance of complex cognitive tasks has been referred to as 'executive attention' or 'cognitive control' (9,39). Similarly, Duncan's (20,40) description of the multiple demand (MD) system theory (20,40) supports the view that EF and Gf share common processes. Essentially, it states that, when performing any set of (complex) actions, a task model is constructed. In this model, task components compete for representation. Adding new components to the model (e.g. new instructions) leads to more competition, making each component less robust or even lost. The efficiency of constructing such a task model is closely related to Gf, especially when task complexity and novelty increase (20). Since the CANTAB tasks are multi-faceted and increase in complexity compared with singular EF tasks (e.g. go/no-go paradigm), they may require more Gf involvement or MD activity, which in turn may explain the strong EF–Gf relation.

Current results have some implications for neuropsychiatric disease and treatment. Clinicians tend to strive for purity of cognitive constructs, which is reflected in commonly used neuropsychological instruments. Leaving the assemblage of Gf and EF out of account, interaction effects between these cognitive abilities, which are essential in the understanding and explanation of pathological behaviour, will be lost. This is in part due to the fact that most EF tasks are developed based on the diverse nature of EF, therefore not focusing on underlying common/general abilities. Following Diamond's (5) and Duncan's (20,40) theoretical position, deficits on task performance do not depend only on separate cognitive task demands, but on their context, that is, how they are put together to set up goal-directed behaviour. Therefore, the assessment of neuropsychological functioning should focus on dissecting the general process and efficiency of rule acquisition and application, next to examining specific cognitive skills necessary for task execution.

Some remarks about task-selection and data collection must be made. First, although CANTAB tasks can be considered as a realistic representation of EF in daily life, complexity seems to play such a crucial part in Gf involvement that utilisation of less multifaceted EF tasks could have resulted in a different outcome. The amount of general cognitive processes versus specific EF demands required for the tasks will influence this overlap. Second, the inclusion of the IED can be debated given its tendency towards a bimodal distribution. However, mental flexibility is of such importance in defining EF, that exclusion would undermine the *a priori* formulated model. Third, data collection was based on convenience sampling. Combining subsamples in one group allows us to include both high functioning and impaired participants and to examine the entire scope of EF and intelligence in a heterogeneous sample. A larger data set may allow future multi-group comparisons, using different psychiatric diagnostic groups and healthy participants, and/or different levels of severity in executive dysfunctioning.

A final comment concerns the theoretical framework. The current study adopts a neuropsychological perspective on EF, and based the model on the Gf–Gc distinction rather than on the more extensive Cattell-Horn-Carroll theory of cognitive abilities (CHC-theory; 41). In the latter, purity of abilities is essential in the psychometric perspective on intelligence, whereas the former neuropsychological view tends to be more integrative in describing different interacting abilities. Indeed, according to Kaufman and Kaufman (24) the fragmentation of intelligence does not contribute to clinical relevance, and therefore, CHC theory was not utilised in the construction of the KAIT. For further reading about CHC theory and neuropsychological constructs, see (41,42).

In sum, results of the present study strengthen earlier findings on overlap of Gf and EF (4,8,43). Following Duncan's theory on the MD system (20,40), cumulating complexity will lead to more involvement of Gf, and may explain the current strong EF–Gf relation. Existing neuropsychological instruments are developed from a multiple-system view and do not separate specific executive task demands and 'higher level' general cognitive control required to execute the task. Furthermore, static outcome measures generally used in neuropsychological assessment do not give insight in the efficiency of task execution. Therefore, Gf dysfunction in neuropsychiatric patients warrants further EF examination and vice versa, to optimally enable discrimination between specific versus general cognitive dysfunctioning. Such a detailed analysis of the process of task execution (using both general intelligence tests as well as neuropsychological instruments) can guide differential diagnosis and lead to a more refined neuropsychiatric treatment indication.

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Author Contributions

All authors have (1) made substantial contributions to conception and design of the study (L.A., E.W.) and acquisition (L.A., E.W.) or analysis (L.A., W.V.) and interpretation of data (L.A., R.K., W.V., and J.E.), (2) drafted the article or revised it critically for intellectual content (L.A., R.K., E.W., W.V., and J.E.) and (3) approved the version to be published (L.A., R.K., E.W., W.V., and J.E.).

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Conflicts of Interest

The authors have no competing interests.

Ethical Standards

The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

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