Intelligence 46 (2014) 107–121

Contents lists available at ScienceDirect

Intelligence

journal homepage:

Relations between speed, working memory, and intelligence from preschool to adulthood: Structural equation modeling of 14 studies

Andreas Demetriou [a,*], George Spanoudis [b], Michael Shayer [c], Sanne van der Ven [d], Christopher R. Brydges [e], Evelyn Kroesbergen [d], Gal Podjarny [f], H. Lee Swanson [g]

[a] University of Nicosia Research Foundation, University of Nicosia, Makedonitissas Avenue, P.O. Box 24005, 1700 Nicosia, Cyprus
[b] University of Cyprus, Cyprus
[c] Kings College, University of London, UK
[d] University of Utrecht, The Netherlands
[e] University of Western Australia, Australia
[f] Carleton University, Canada
[g] University of California, USA

ARTICLE INFO

Article history:
Received 19 December 2013
Received in revised form 20 May 2014
Accepted 20 May 2014
Available online xxxx

Keywords:
Cognitive development
Fluid intelligence
Processing speed
Reasoning
Working memory

ABSTRACT

We posit that fluid intelligence (Gf) develops in four cycles, with two phases in each cycle, each distinctly connected with changes in processing speed and working memory. New representational units emerge in the first phase of each cycle at 2–4 (representations), 6–8 (inference based concepts), and 11–13 years (principles) and they are integrated into wider systems in the second phase, at 4–6, 8–11 and 13–16 years. We hypothesized that cycle transitions are better predicted by speed and phase transitions by working memory. To test this hypothesis several published studies were selected which measured speed, WM, and Gf at one or more of the age phases concerned. In structural equation models applied on each phase speed was regressed on age, working memory was regressed on age and speed, and Gf was regressed on all three. In line with the hypothesis, in the first phase of each cycle the speed–Gf relations were high and WM–Gf relations were low; this pattern was inverted in the second phase. The role of executive processes strengthened in the second phase of all cycles. The implications for developmental and differential theories of intelligence are discussed.

There is general agreement that human intelligence involves information integration processes activated when dealing with new information or problems. Inference, inductive or deductive, rule bound or heuristic, is a major part of these processes. It underlies psychometric fluid intelligence (Gf) (Carroll, 1993; Jensen, 1998; Spearman, 1927) and problem solving and reasoning studied by developmental (Case, 1985; Halford, Wilson, & Phillips, 1998; Piaget, 1970) and cognitive researchers (e.g., Johnson-Laird, 2013; Rips, 2001). Information processing theories of human intelligence maintain that individual or developmental differences in Gf reflect differences in processing speed (Jensen, 1998) or working memory (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle, Tuholski, Laughlin, & Conway, 1999; Kyllonen & Christal, 1990).

However, the exact role of speed and working memory is still debated. Some researchers emphasize speed as a purer index of the quality of information processing in the brain (e.g., Jensen, 1998). This interpretation is based on studies which estimate the relation between speed and intelligence

* Corresponding author.
E-mail addresses: ademetriou@ucy.ac.cy, demetriou.a@unic.ac.cy (A. Demetriou).

http://dx.doi.org/10.1016/j.intell.2014.05.013
0160-2896/

without involving working memory. Others emphasize working memory because it is the workspace of thinking (Kyllonen & Christal, 1990). Studies emphasizing working memory usually measure all three constructs in young adults, when working memory is the dominant predictor of Gf, according to the patterns to be described below. Finally, others assume a causal linear relation between them such that changes in speed cause changes (or differences) in working memory which, in turn, cause changes (or differences) in Gf (Case, 1985; Coyle, Pillow, Snyder, & Kochunov, 2011; Kail, 1991; Kail & Ferrer, 2007). However, this chain of relations may only reflect the fact that working memory tasks are both timed, like speed tasks, and require information management, like Gf tasks, rather than a causal sequence. In fact, there is evidence that control of attention is common to all, speed, WM, and Gf, explaining their relations (Cowan, Morey, Chen, & Bunting, 2007; Engle et al., 1999; Stankov & Roberts, 1997).

Table 1
Summary of the studies selected for modeling in reference to selection criteria.

Study/data type	Age group/ phase	N	Speeded performance/inhibition	Working memory	Cognition
Miller & Vernon (1996) Correlations/SD	4–6	109	Visual matching (speed)	Recall of color or shape sets presented sequentially or simultaneously	Gf: Object assembly, picture completion, block design
Podjarny et al. (2013) Correlations/SD	4–6	66	2 day/night Stroop-like and a dragon inhibition tasks (inhibition/control)	Forward digit span, backward digit span, counting and labeling	Raven-like matrix task, DCCS, Flexible item selection
Astle et al. (2013) Correlations/SD	4–5	69		Counting and labeling, corsi	DCCS, using maps to locate an object in a room (dual representation)
Bernstein et al. (2007) Raw data	3.5–5.5	72	day/night Stroop-like task (inhibition)	Counting and labeling, BDS	DCCS, theory of mind, false belief
van der Ven et al. (2012) Raw data	Four waves at 6.5, 7.1, 7.5 and 8.1 years	211	Three congruent (speed) and three incongruent (inhibition/control) Stroop-like animal and figure recognition, and Simon task	Backward digit span (BDS), odd-man out, keep-track	DCCS, category shifting guided by color prompt, trail making
Joined Kail (2007), and Fry & Hale (1996) Raw data	6–7 8–10 11–13 14–adult	91 216 119 109	Visual matching Cross out	Reading span Listening span	Raven test
Swanson & Kim (2007) Correlations/SD	Two waves tested at 7 and 8 years	353	Digit naming, letter naming (speed)	STS: FDS, word span, pseudoword span, updating. WM: Listening Sentence Span, Semantic Association Span, Digit/Sentence Span, BDS, Corsi-like, mapping directions task	Semantic based word problems, WISC mental calculation word problems, retrieved processing components of word problems, computational fluency
Berg (2008) Correlations/SD	8–12	95	As above	As above	As above
Brydges et al. (2012) Correlations/SD	7 9	215 95	Visual discrimination (speed) incongruent Stroop, and RT to go/no-go tasks (inhibition/control)	BDS, Letter–number sequencing, sentence repetition	Gf: Cattell culture fair test (i.e., series completion, matrices, odd-one out, topology), WISC block design Gc: WISC picture naming, word definitions, information. Fluency: WCST, verbal fluency, letter monitoring
Nettlebeck & Burns (2010) Raw data	8–10 11–13 14–30 31–80	118 84 105 169	WISC digit symbol, Woodcock visual matching, inspection time, simple RT, Odd-man out (speed)	Mental swaps Picture recognition WISC FDS	Cattell culture fair test
Demetriou et al. (2005) Raw data	8–10 12–14	60 60	Three congruent (speed) and three incongruent (inhibition/control) Stroop-like verbal, numerical, and figural tasks	Word FDS, Digit FDS, Visuo/ spatial WM, simple listening WM span	Inductive and deductive verbal, spatial, and mathematical reasoning,
Leonard et al. (2007) Correlations/SD	14	204	Simple visual identification, perceptual discrimination (speed), visual identification under mental rotation (control)	Pseudoword FDS, Woodcock auditory working memory, simple listening WM span task	Gf: WISC block design, picture completion tests. Language: Vocabulary, discourse understanding
Rijsdijk et al. (1998) Correlations/SD	16	213	Letter, digit recognition (speed), and choice RT (control)	WISC digit span, coding	Gf: Picture completion, picture arrangement, block design, object assembly. Gc: Information, comprehension, arithmetic