ARTICLE IN PRESS
INTELL-00827; No of Pages 6
Intelligence xxx (2013) xxx–xxx
Contents lists available at ScienceDirect
Intelligence
journal homepage:

Developmental intelligence: From empirical to hidden constructs

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ARTICLE INFO

Article history:
Received 21 June 2013
Accepted 16 July 2013
Available online xxxx

Keywords:
Cognitive development
Intelligence
Speed of processing
Variability
Working memory

ABSTRACT

This article answers some of the criticisms and suggestions of the three commentaries. We showed, in agreement with Coyle, that (i) variability is indeed distinct from speed, (ii) they both additively reflect processing efficiency and (iii) that they differentially relate to WM and gf during development. In agreement with Kail, we showed that developmental intelligence and psychometric intelligence are (i) related but distinct, they additively contribute to school learning and (iii) their role varies with developmental phase. Finally, in agreement with Pascual-Leone, we proposed a number of higher level hidden constructs to account for the data patterns observed between empirical constructs, such as speed, variability, WM, and reasoning.

1. Introduction

Intelligence is an elusive construct because, contrary to Boring (1923), there is much more in it than what the tests measure: processing efficiency, attention, executive control and mental flexibility, working memory, inference (inductive, deductive, and abductive), planning, learning, and decision making. Research in different disciplines or traditions focused on some of these components but integrative research is rare. The psychometric tradition emphasizes individual differences in learning and dealing with novelty. Cognitive researchers focus on the mental processes in learning and thinking. Developmental researchers study their development. In our research we attempt to integrate the three traditions in a comprehensive theory that would specify the mental processes involved in intelligence and account for their organization and development.

The target article (Demetriou et al., 2013) presented three studies which investigated how speed of processing, working memory, and inference (i.e., deductive and inductive reasoning and problem solving in various domains, or gf), develop and interact from 4 to 16 years of age. We showed that processes are organized in two major levels, an efficiency level defined by speed and control and a representational level defined by WM and *gf*, which are increasingly differentiated with development. Speed increases with age from 4 to 13 years, leveling off thereafter (until young adulthood), but its relation with gf is mediated by WM. WM always relates to speed and gf, but it accounts mainly for individual differences in gf rather than developmental changes in it. All processes develop in cycles marked by changes in the nature and integration of representations. Changes in speed reflect major changes in the nature of representations and changes in working memory reflect changes in their integration.

We are honored by the decision of Douglas Detterman, the Editor of *Intelligence*, to invite commentary on this paper. And we are grateful to our commentators, Thomas R. Coyle, Robert V. Kail, and Juan Pascual-Leone, for their constructive commentaries. They all raise important issues which may move the field forward, if satisfactorily answered. Some of them are empirical and some are conceptual. Empirical issues are resolved by evidence. Conceptual issues may be resolved through constructs that would enhance our understanding of phenomena and open new empirical issues to be resolved by

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0160-2896/$ – see front matter
http://dx.doi.org/10.1016/j.intell.2013.07.014

further research. In this rejoinder we will first respond to the empirical issues and then elaborate on the conceptual issues. Coyle (in press) suggests that we may have underestimated the role of speed because we used rather simple tasks and ignored variability of reaction times (RTSD). Following Jensen (1998, 2006), he suggested that RTSD may be an important aspect of processing efficiency because it reflects neural efficiency in information processing better than speed. Kail (in press) suggests that the theory must expand to cover younger and older age spans than those covered by the target article. Moreover, he proposes that the theory must be tested in more real-life situations, such as school learning. Pascual-Leone (in press) suggests that we need to move beyond empirical demonstrations of patterns and relations to underlying hidden constructs than may unify the processes involved and allow the discovery of underlying integrative powers. We will answer these issues in turn.

2. Speed and variability in processing efficiency and development

Speed of processing is an index of neural efficiency in registering and processing information (Jensen, 1998). Individual and developmental differences in psychometric intelligence reflect, to a significant extent, differences in the quality of information processing. This is the reason why speed is a relatively good predictor of both individual and developmental differences in intelligence. In the target article we showed that the power of speed wanes with age and when it is strong it is mediated by working memory, becoming redundant as a predictor when working memory is taken into account. We suggested that this is due to the fact that speed and WM share common components, such as attention. Also, WM tasks are to some extent speeded tasks because storage and recall of information occur under time limitations. Coyle, based on Jensen (1998, 2006), suggested that variability of speed of processing may be a distinct, if not a better, index of neural efficiency because it reflects processing cohesion and control: the lower the better.

We used the measures of Studies 2 and 3 to investigate the role of variability. Children in Study 2 were examined by five types of speeded performance tasks of systematically increasing complexity: Simon-like tasks requiring location identification (Speed, 2 tasks), Stroop-like tasks requiring letter or digit recognition (i) without (Perceptual Discrimination (PD1), 4 tasks) and (ii) with interference (Perceptual Control, PC, 4 tasks), and object recognition tasks requiring object recognition (i) without (PD2, 3 tasks) (ii) and with conceptual interference (Conceptual Control (CC), 3 tasks). All tasks are described in detail in Demetriou et al. (2008), (2013). We estimated variability according to the method proposed by Jensen (2006). That is, we first estimated the individual sd for each of the five task groups above and then estimated variability according to the Eq. (1) below:

$$\text{Mean RTSD} = \sqrt{}(\text{SD}_1)^2 + \ldots + (\text{SD}_n)^2)/n. \quad (1)$$

To test if variability is a factor of mental efficiency in addition to speed and working memory, we tested Model B described in the target article (Demetriou et al., 2013) including variability, in addition to the other factors. Specifically, this model included three indexes of speed (PD, PC, and CC), three indexes of variability (the SD for each of these measures), three indexes of working memory (visual WM, and two versions of Case's working memory task for numbers), and two indexes of gf (inductive and deductive reasoning). The model is shown in Fig. 1 (with fit indexes). It can be seen that speed and variability were regressed on age, WM was regressed on speed and variability, and gf was regressed on speed, WM, and variability. This model was first tested on the total sample which included 395 children (about equally drawn among first through sixth primary school grade (mean age 6.6 to 11.6 years, respectively)). The model was also tested in a 2-group analysis, where the first group included grades 1–3 (199 participants) and the second included grades 4–6 (196 participants). In this model, the relations of variables to factors were constrained to be equal across the two groups and the between factors relations were allowed to vary freely.

In the model applied on the total sample, the effect of variability on WM (−.45) and gf (−.23) was significant. In the 2-group model, in the 6–8 years old children, the effects of both variability (−.43) and speed (−.49) on gf were significant and relatively high. However, in the 8–11-year olds, both effects on gf were low (−.22 and −.20, respectively) but the effect of WM on gf (.43) was much higher. Interestingly, however, variability effects on WM were about the same in the two age groups (−.41 and −.39, respectively) and much higher than the effects of speed (−.17 and −.15, respectively). Therefore, variability indeed is, as suggested by Coyle, a factor influencing WM and gf on top of speed. In line with the theory proposed in the target article, these effects are stronger in the 6–8 than in the 9–10 years of age phase, suggesting that important changes in mental cohesion occur in the first rather than in the second phase of a period, when a new mental unit is formed.

We tested these relations on the measures of Study 3, which covers development in adolescence. In this study, variability was estimated over four groups of compatible and incompatible Stroop-like tasks, each including three tasks (dominant stimulus recognition-compatible, dominant geometric figure recognition made of the same figure, component figure (letter) recognition-interference from the dominant figure (letter), component figure (letter) recognition-interference from the dominant figure (number)). The model described above was tested on the performance attained by Cohorts 2, 3, and 4 at second (when they were 11, 13 and 15 years old) and third testing (when they were 12, 14 and 16 years old). The relations obtained are shown in Fig. 1. It can be seen that the effects of speed on WM (−.70) and gf (−.61) were strong. Also, the effect of WM on gf was very high (.79). However, the effects of variability on WM (−.18) and gf (.0), were very low, suggesting that cognitive changes in adolescence are not associated with variability. Fig. 2 shows that this is due to the fact that no important changes occur in variability after the age of 11 years. It can be seen that variability decreases in two steps, from 6 (.36 s) to 8 years (.23 s) and then again from 10 (.22 s) to 11 years (.16), settling at this level thereafter. Obviously, changes in variability co-occur with changes in the kind of concepts gf can handle.

In conclusion, the appearance of speed and variability as distinct factors with different effects on WM and gf supports