Increasing fluid intelligence is possible after all

Robert J. Sternberg*
Office of the Dean of the School of Arts and Sciences, Tufts University, Medford, MA 02155

Almost 40 years ago, Jensen (1) claimed that, when all is said and done, there is not much one can do to raise people's IQs. Over the years, there have been various attempts to do so, which generally have yielded somewhat ambiguous results (2). Even successful attempts (3) have typically involved training people on the same kinds of items on which they would be tested, so that it was not clear whether the training was generalizable, rather than merely a result of practice effects on particular item types (4).

Further complicating the picture have been studies showing that IQ tends to be fairly highly heritable, with most reliable estimates ranging from ≈0.5 to 0.8 (5). More recently, heritability has been found to vary both with age, with IQ becoming more highly heritable in later years (6), and with social class, with IQ more highly heritable in higher social classes (7). Although heritability does not imply the fixedness of a trait (e.g., height is highly heritable but also modifiable), the mixed results of training studies have been taken to be consistent with the notion that IQ is relatively fixed.

IQ may be viewed as a composite comprising multiple elements: In many theories of intelligence, a distinction is made between fluid and crystallized intelligence (8). Fluid intelligence comprises the set of abilities involved in coping with novel environments and especially in abstract reasoning; crystallized intelligence is the product of the application of these processes. Fluid intelligence is often measured by tests such as figural analogy, classification, and matrix problems, whereas crystallized intelligence is measured by tests of vocabulary and general information (9).

Increasing Fluid Intelligence

In this issue of PNAS, Jaeggi *et al.* (10) have made an important contribution to the literature by showing that (*i*) fluid intelligence is trainable to a significant and meaningful degree; (*ii*) the training is subject to dosage effects, with more training leading to greater gains; (*iii*) the effect occurs across the spectrum of abilities, although it is larger toward the lower end of the spectrum; and (*iv*) the effect can be obtained by training on problems that, at least superficially, do not resemble those on the fluid-ability tests. Their study therefore seems, in some measure, to resolve the debate over whether fluid intelligence is, in at least some meaningful measure, trainable.

Given these positive results, a reader might wonder why it has taken nearly 40 years to show training effects. Why the wait? The reason is, in large measure, that recent cognitive-based theories of intelligence have provided new insights into just what kind of training would be successful. It is only in fairly recent years, relative to the age of the field, that so-called "working memory" has come to be viewed as a key determiner of fluid intelligence (11). Working memory is usually viewed as that part of long-term memory that is available for active information processing, including placement of information into and retrieval of information out of storage. Tasks such as backward digit span and the *n*-back task used in this study are good measures of working memory (12). So the basic idea in Jaeggi *et al.*'s study (10) is that one can use modern cognitive theory to serve as a basis for training, which should then produce a training regimen that will make a meaningful difference. This idea proved to be correct.

Fluid intelligence is trainable to a significant and meaningful degree.

Jaeggi *et al.*'s article (10) is important to the field of intelligence because it shows that training can improve fluid intelligence, can do so across intelligence levels, and can do so in a theory-based way. To the extent that past investigators failed to obtain such robust results, it appears to be because they failed to use the cognitive–theoretical basis that served as the basis for training in Jaeggi *et al.*'s study. These results have important educational-policy implications, because they suggest that the results of conventional tests of intellectual abilities and aptitudes provide indices that may be dynamic rather than static and modifiable rather than fixed. Most researchers have viewed intelligence as largely fixed (13), although others have argued strongly for its modifiability (14). The latter are shown to be justified in their beliefs.

Further Research

There will be a need for follow-up on these interesting results because of several limitations of Jaeggi *et al.*'s study (10), none of them calling into question the obtained results. Eight are of some concern.

First, with regard to the main independent variable, there was only one training task in the study, so it is unclear to what extent the results can be generalized to other working-memory tasks. It would be important to show that the results are really about working memory rather than some peculiarity of the particular training task.

Second, with regard to the main dependent variable, there was only one kind of fluid-ability test, geometric matrix problems from various tests of the kind found in the Raven Progressive Matrices (15) and similar tests. It would be important to show that the results generalize to other fluid-ability tasks rather than being peculiar to this kind of task. Matrix problems are generally considered to be an excellent measure of fluid intelligence (16), but they do place a particularly great demand on working memory. At the same time, fluid-ability tests tend to be highly correlated with each other (17), so generalization would appear likely. Whether generalization extends beyond the matrix tests to other kinds of cognitive tests, such as of spatial, numerical, or other abilities, remains to be seen.

Third, it is important to remember that the fluid-ability tests, although the dependent variables in Jaeggi *et al.*'s study (10), were originally intended to be independent variables in predicting meaningful behavior in the real world (18). Such behavior would include, among other things, educational and occupational achievement. Tests of intelligence have also been shown to have implications for other kinds of success, including even health-related behavior (19). So it would be useful to show that the training transfers to success in meaningful behaviors that extend beyond the realm of psychometric testing.

Author contributions: R.J.S. wrote the paper.

The author declares no conflict of interest.

See companion article on page 6829.

*E-mail: robert.sternberg@tufts.edu.

Fourth, Jaeggi *et al.* (10) mention that, with training, the value of fluid intelligence for predicting performance on other tasks can change. It would be important to show that the predictive power of the fluid-ability tests, after training, is at least as high as or possibly even higher than it was before training took place.

Fifth, as Jaeggi *et al.* (10) recognize, their study does not address whether the training is durable over extended periods of time. Too often increases of intelligence obtained through training programs have proved to be fleeting (20). Future work would need to assess durability over varying periods of extended time.

Sixth, the control group in Jaeggi *et al.*'s study (10) had no alternative task, which can lead readers to query whether a placebo treatment in an additional control group might have led to a stronger comparison. In future work, one would want to include a training alternative that teaches something expected not to be relevant to performance on the fluid-ability tests.

Seventh, because there is only one study, there is a great need for replication. In single studies, one can never be sure whether there are aspects of the design or procedure that lead to results that later prove not to be replicable.

Finally, the effects need to be examined on a much wider range of ability levels and, in general, of types of participants than were tested in this study. The subjects were all recruited from the University of Bern community, which is likely to be a rather selective sample of individuals not typical of the population either of Switzerland or, more generally, of developed countries or certainly the world. It would be particularly important to test elderly people, who are at risk for loss of fluid ability. The sample was also relatively small ($n = 70$).

None of these criticisms detracts from the central importance of the results of Jaeggi *et al.*'s study (10). On the contrary, they suggest that their study should and probably will be the first in a long series instigated by this pioneering research.

1. Jensen AR (1969) How much can we boost IQ and scholastic achievement? *Harvard Edu Rev* 39:1–123.
2. Detterman DK, Sternberg RJ, eds (1982) *How and How Much Can Intelligence Be Increased?* (Erlbaum, Mahwah, NJ).
3. Kramer AF, Willis SL (2002) Enhancing the cognitive vitality of older adults. *Curr Directions Psychol Sci* 11:173–177.
4. Detterman DK, Sternberg RJ, eds (1993) *Transfer on Trial: Intelligence, Cognition, and Instruction* (Ablex, Norwood, NJ).
5. Plomin R (2004) *Nature and Nurture: An Introduction to Human Behavioral Genetics* (Wadsworth, Thousand Oaks, CA).
6. Plomin R, DeFries JC, McClearn GE, McGuffin P (2008) *Behavioral Genetics* (Worth, New York), 5th Ed.
7. Turkheimer E, Haley A, D'Onofrio B, Waldron M, Gottesman II (2003) Socioeconomic status modifies heritability of IQ in young children. *Psychol Sci* 14:623–628.
8. Carroll JB (1993) *Human Cognitive Abilities: A Survey of Factor-Analytic Studies* (Cambridge Univ Press, New York).
9. Mackintosh N (1998) *IQ and Human Intelligence* (Oxford Univ Press, New York).
10. Jaeggi SM, Buschkuehl M, Jonides J, Perrig WJ (2008) Improving fluid intelligence with training on working memory. *Proc Natl Acad Sci USA* 105:6829–6833.
11. Engle RW, Tuholski SW, Laughlin JE, Conway ARA (1999) Working memory, short-term memory, and general fluid intelligence: A latent variable approach. *J Exp Psychol General* 128:309–331.
12. Kane MJ, Engle RW (2002) The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual differences perspective. *Psychonom Bull Rev* 9:637–671.
13. Jensen AR (1998) *The G Factor* (Praeger, Westport, CT).
14. Feuerstein R (1980) *Instrumental Enrichment: An Intervention Program for Cognitive Modifiability* (University Park Press, Baltimore, MD).
15. Raven J, Raven JC, Court JH (2003) *Manual for Raven's Progressive Matrices and Vocabulary Scales. Section 1: General Overview* (Harcourt Assessment, San Antonio, TX).
16. Anastasi A, Urbina S (1997) *Psychological Testing* (Prentice–Hall, Englewood Cliffs, NJ), 7th Ed.
17. Cattell RB (1971) *Abilities: Their Structure, Growth, and Action* (Houghton Mifflin, Boston).
18. Binet A, Simon T (1916) *The Development of Intelligence in Children*, trans Kite ES (Williams & Wilkins, Baltimore, MD).
19. Gottfredson LS, Deary IJ (2004) Intelligence predicts health and longevity, but why? *Curr Directions Psychol Sci* 13:1–4.
20. Spitz HH (1992) Does the Carolina Abecedarian Early Intervention Project prevent sociocultural mental retardation? *Intelligence* 16:225–237.