10 quick questions about processing speed

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The third in the series of British Academy Debates on Ageing – 'The Best Years of Our Lives? Body, Brain and Well-being' – was held in Edinburgh. On 30 April 2014, as a satellite event, the British Academy held a small expert workshop entitled *Is the World Too Fast When We Are Slowing Down?* In this article, the two convenors describe the issues that the workshop wrestled with.

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There is a beautiful incongruence about the human mental capability that psychologists call processing speed.

On the one hand, the tests that are used to assess it are basic and apparently irrelevant to the cognitive functions we should think would be important. How quickly can you write down the symbols that correspond to a number-symbol code? How quickly can you press the correct computer key when a number '3' appears on the screen? Two vertical lines are flashed in front of you for 30-thousandths of a second; can you tell which one is much longer than the other? There's nothing there that seems to be relevant to the higher thinking powers, or to the complexity of everyday life.

On the other hand, these simple tests have remarkable predictive powers. They correlate strongly with complex cognitive skills such as reasoning. They decline with age, and some argue that their ageing drives the ageing of most other complex mental capabilities. They are also associated with how long people live.

Given this set of facts, one would think that there would be a more co-ordinated research programme on this important and interesting human difference. It interests us. One of us (IJD) has been conducting research on processing speed since his undergraduate dissertation in 1980, and one of us (SJR) has a research fellowship to study it. Indeed, processing speed has been around since the beginning of experimental psychology. When James McKeen Cattell first suggested a battery of ten 'Mental Tests and Measurements' in the journal *Mind* in 1890, two were reaction time tests.[1] However, another remarkable fact about processing speed is how many questions about it are still unanswered, or even largely unaddressed.

The British Academy provided the support to help to correct this. As a part of its series of British Academy Debates on *Ageing*, the debate held in Edinburgh addressed the ageing mind and body. Allied to that successful meeting, the Academy encouraged us to hold a relevant event, run by a young scientist (SJR). So we invited international and national experts to address what we thought were the main questions about processing speed. They accepted; they came. For an intense day, we sat round a table in the Royal Society of Edinburgh's (RSE) Kelvin room, under the benign gaze of Nobel Laureate Peter Higgs's portrait (Figure 1). Here, our 'twelve angry men' – we invited some women, but they could not come – tried to answer our '10 quick questions about processing speed'. Actually, there were twelve psychologists, and Professor James Goodwin from Age UK, who was specially invited to reflect on the practical implications and impact of processing speed research for older people.

Each psychologist gave a short talk on an aspect of processing speed. Their brevity meant that there was much time for discussion. The talks and discussion were recorded, with the aim of our producing a peer-reviewed journal editorial-manifesto for processing speed research, with an emphasis on its relevance to ageing. And in this issue of the *British Academy Review* we aim to provide a pithy statement of the 10 questions and some brief reflections on them. We cannot adequately report the contributions made by the workshop attendees. Instead, we mention them below in association with some important facts and ideas.[2]

1. J. McKeen Cattell, 'Mental Tests and Measurements', *Mind*, 15 (1890), 373-81.
2. If you would like more detail, one of those attending the workshop – James Thompson – has uploaded the slides from several of the talks and provided a commentary on each on his blog: http://drjamesthompson.blogspot.co.uk

How do we measure processing speed?

As we suggested earlier, there is heterogeneity in how processing speed is measured. There are paper-and-pencil tests, there are button-pressing reaction time tests, and there are lower-level sensory efficiency (psychophysical) tests. A limitation of this variety is that there is no guarantee that these measure the same thing, despite the fact that they all attract the same epithet of 'processing speed'; it is an empirical question as to whether they pick up the same human differences. A strength of all of the types of test used is that, compared with IQ-type tests – with which they are correlated – they appear to be more culture-free. James Thompson and Elliot Tucker-Drob emphasised that tests of processing speed do not seem to be affected by socioeconomic and educational differences in the same way as other intelligence test measures.

Figure 1
The participants at the British Academy workshop 'Is the World Too Fast When We Are Slowing Down?', held at the Royal Society of Edinburgh on 30 April 2014. Standing (left to right): Geoff Der, Thomas Espeseth, Tim Croudace, James Thompson, James Goodwin, Stuart Ritchie (organiser), Paul Verhaeghen, Rogier Kievit, Elliot Tucker-Drob, Ian Deary FBA FRSE. Seated (left to right): Patrick Rabbitt, Mark Bastin, Nicholas Mackintosh FRS. The portrait of Peter Higgs is by Victoria Crowe FRSE.

Should we standardise measurement of processing speed?

An obvious, and scientifically pure, response to there being a Babel of processing speed tests is to aim at standardisation. However, among others at the meeting, Patrick Rabbitt warned us that there is no such thing as a pure psychometric test, one that achieves isomorphism between test score and a single human cognitive capability. This failure of identity between test and mental process has long been a concern of Ian Deary.[3] Thus, some tests of processing speed also assess abilities such as memory and motor performance. Perhaps, then, studies should converge on a small set of consistent measures that are all aimed at measuring the same construct? Some attempts (including by us) have been made to develop free software that would standardise the measurement of reaction time,[4] and this could also be done in future for other processing speed measures. It is Tim Croudace's vision to provide a computer platform that would provide measures of processing speed that would be downloadable by researchers and applied to large cohort studies.

How does speed develop across the life course?

After a vast increase throughout child development up until the age of around 20, many cognitive abilities decline on average with age. How does processing speed fare in comparison with the others? Tucker-Drob used data from psychometric test standardisation samples to show that processing speed declines more quickly than any other cognitive domain (Figure 2). Geoff Der and Ian Deary showed that, in the large UK-based Health and Lifestyle Study that tested thousands of people from age 18 to over 80, choice reaction time slowed steadily from early adulthood.[5] So, there is good reason to describe ageing as 'slowing down'.

What is the role of speed in intelligence differences?

Do differences in how fast and efficiently the brain can process information associate with differences in 'higher' cognitive abilities, like reasoning, problem solving, and memory? The answer is yes; there are moderately strong correlations between tests like reaction time and sensory processing efficiency and higher-level tests of intelligence. Nicholas Mackintosh warned that we should be wary of the correlation-causation fallacy. Because processing speed is reliably correlated with intelligence does not mean that processing speed underlies intelligence, even if processing speed measures appear to be more 'basic' than the 'higher' cognitive functions tapped by IQ tests. The relation may be the opposite way around, or slower speed and lower intelligence might be caused by a third variable and they may not cause each other. One way of testing causality might be to show that training people

3. I.J. Deary, *Looking Down on Human Intelligence* (Oxford, Oxford University Press, 2000).
4. I.J. Deary *et al.*, 'A Free, Easy-to-use, Computer-based Simple and Four-choice Reaction Time Programme: The Deary-Liewald Reaction Time Task', *Behavior Research Methods*, 43 (2011), 258-68.

5. G. Der and I.J. Deary, 'Age and Sex Differences in Reaction Time in Adulthood', *Psychology and Aging*, 21 (2006), 62-73.

Figure 2
Elliot Tucker-Drob of the University of Texas at Austin presenting findings on age-related changes in cognitive abilities, and emphasising that processing speed begins to decline notably early and strongly compared with other mental abilities.

on processing speed tasks, and improving their speed, leads to more general increases on cognitive tasks. Paul Verhaeghen described some such interventions, which are meta-analysed in his recent book.[6] They show that effects of speed practice are 'local' and do not 'transfer' to other cognitive functions.

What is the role of speed in cognitive ageing?

In a famous paper in 1996, psychologist Timothy Salthouse theorised that how people slowed in their simple processing speed could account for most of the ageing differences in other mental domains.[7] Thus, processing speed was the master mechanism by which much of human cognitive ageing took place. Stuart Ritchie presented results from a large cohort study, showing a high correlation between decline in a very basic measure of speed, visual inspection time, and decline in fluid intelligence.[8] Such data are compatible with speed-as-master-mechanism in cognitive ageing, but are not sufficient to prove it. Tucker-Drob reminded the meeting that most cognitive tasks appear to decline together in old age.[9] This includes processing speed. What is difficult is to show that speed has some privileged causal position among them. It is not enough just to point to the fact that speed tests look simpler than other cognitive tasks. Salthouse's more recent work shows changes in several cognitive domains, and processing speed is just one among them. Speed, then, even for the one-time major speed theorist, has lost its privileged place in the model. On the other hand, Verhaeghen's recent book-length work in collating and meta-analysing processing speed study results does point to a 'general slowing' model that is a good summary of the data. However, a model that allows for more details provides an even better summary.

6. P. Verhaeghen, *The Elements of Cognitive Ageing* (Oxford, Oxford University Press, 2014).
7. T.A. Salthouse, 'The Processing-speed Theory of Adult Age Differences in Cognition', *Psychological Review*, 103 (1996), 403-28.
8. S.J. Ritchie *et al.*, 'A Strong Link Between Speed of Visual Discrimination and Cognitive Ageing', *Current Biology*, 24 (2014), R681-683.
9. E.M. Tucker-Drob, 'Global and Domain-Specific Changes in Cognition Throughout Adulthood', *Developmental Psychology*, 47 (2011), 331-43.

Generality of speed from senses to central processing?

One question posed was whether people are generally faster or slower in various aspects of brain function. It received little response. It deserves more.

Validity of speed-fractionating theories?

The next three questions are about the foundations of processing speed. It should be admitted that a summary processing speed score – whether that is a test score or a reaction time – is complex. Can we understand its elements? Cognitive psychologists have tried to do this by applying mathematical models to reaction time results to retrieve what they consider to be lower-level parameters that have validity in terms of brain function. Thomas Espeseth was a supporter of this reductionist idea that researchers might gain 'purchase' on the question of processing speed by fractionating processing speed tasks into different components. Getting to a finer-grained level would allow more detailed questions to be asked about the specific biological mechanisms that underlie processing speed. The unanswered question here is whether the mathematically-derived parameters validly reflect aspects of brain processing.

What are the brain foundations of processing speed?

Perhaps it might be better to go to the brain's biology for the foundations of processing speed rather than the way-station of cognitive theories' parameters. Many of the efforts to understand processing speed at the level of the brain have focused on the brain's white matter (its connecting fibres), since it transmits information between regions of the brain that are important for complex thought. Mark Bastin explained that people with healthier white matter tend to have higher intelligence, and this association is largely explained by processing speed.[10] Rogier Kievit described an elegant theoretical perspective he called the 'watershed model'

whereby processing speed is an intermediate phenotype between white matter and intelligence, and supported it with complex statistical models.

Genetic foundations of processing speed?

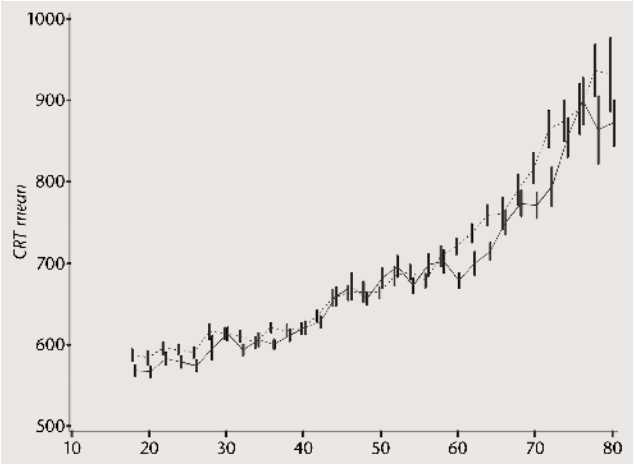
Like all cognitive abilities, variation in processing speed among people is partly influenced by genetic differences. We know this from twin studies, including many at Australia's Queensland Institute of Medical Research, whose population samples have good measures of processing speed. But we do not yet know the specific genes that are involved. Candidate gene studies and genome-wide association studies are currently under way in an attempt to find these specific variants. Deary described some new, yet-to-be published analyses from a large-scale, international consortium project that is seeking the genetic contributions to processing speed involving more than 10,000 subjects.

What are the practical implications of processing speed research?

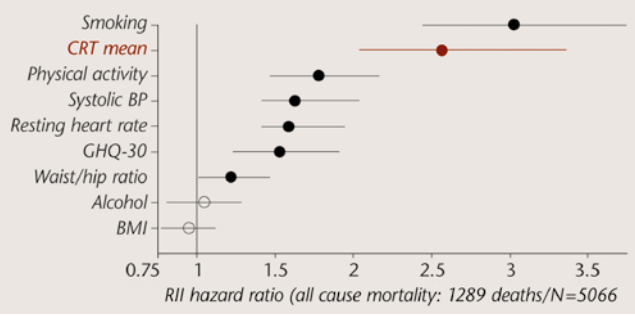
Does processing speed have a major impact on people's lives? Tucker-Drob reminded the meeting that decline in cognitive abilities, as measured by IQ-type tasks, correlates strongly with decline in 'everyday' abilities such as calculating the right change and following a recipe.[11] Deary asked the meeting: what could be more important a practical outcome than death? Deary and Der summarised their results that had shown that a processing speed measure (choice reaction time) explained two-thirds of the relationship between intelligence and mortality (whereby smarter people tend to die later; Figure 3).[12] This gives the lie to the classic refrain of 'live fast, die young' – the results point in the opposite direction.

We commend James Goodwin – a processing speed ingénue at the start of the workshop – for absorbing so much so quickly, and for providing an elegant closing overview from the point of view of the workshop's knowledge-exchange value for older people. We did eventually open the doors of our RSE room and allow our angry men to leave. We think the meeting did its job. Scientific constructs sometimes need a nudge. Processing speed has so many intriguing findings, as we hint in our 10 questions above, that it deserves to be vindicated or vanquished. In the meantime, it is frustrating to see its relevance to intelligence, ageing, brain health, and death, and yet to see that it is a sideline for researchers rather than their main activity. Psychology is not so flush with good constructs that is can afford to ignore those that have as good a 'nomological network' as does processing speed. But it needs integrating as a larger research programme. Those new researchers who buy this classic construct will find that it has had many owners, some more careful than others, but that it is still a good runner.

Figure 3
Two powerful demonstrations of the relevance of processing speed. Both are from the UK's Health and Lifestyle Survey (HALS).



The diagram above shows the slowing of choice reaction time (CRT) from age 18 to about 80. (Continuous lines are men and dashed lines are women; vertical lines are standard errors.) Whereas the average 18-year-old takes less than 0.6 of a second to decide correctly which of four numbers was shown on a small screen, the average 80-year-old takes about 0.9 of a second. (From G. Der and I.J. Deary, 'Reaction time age changes and sex differences in adulthood. Results from a large, population based study: the UK Health and Lifestyle Survey', *Psychology & Aging*, 21 (2006), 62-73.)



The diagram above shows how strongly the same choice reaction time test (CRT) predicts death in about 20 years of follow-up of about 7000 people in the HALS. (The dots are the 'relative index of inequality' – the strength of the predictor; the horizontal lines are the 95 per cent confidence intervals.) Smoking is the strongest predictor. Choice reaction time comes next, a stronger predictor of mortality than several other, well-known risk factors (BP is blood pressure; GHQ is a self-report questionnaire of psychological distress). A value of 1 on the x-axis means that there is no predictive power, as is seen here for alcohol drinking and body mass index (BMI). Results are adjusted for the age and sex of the participants. (From B.A. Roberts, G. Der, I.J. Deary and G.D. Batty, 'Reaction time and established risk factors for total and cardiovascular disease mortality: comparison of effect estimates in the follow-up of a large, UK-wide, general-population based survey', *Intelligence*, 37 (2009), 561-566.)

10. L. Penke *et al.*, 'Brain White Matter Integrity as a neural Foundation for General Intelligence', *Molecular Psychiatry*, 17 (2012), 1026-30.
11. E.M. Tucker-Drob, 'Neurocognitive Functions and Everyday Functions Change Together in Old Age', *Neuropsychology*, 25 (2011), 368-77.
12. I.J. Deary and G. Der, 'Reaction Time Explains IQ's Association with Death', *Psychological Science*, 16 (2005), 64-9.

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