**31 December 2016**

# When to teach what: are there sensitive periods for learning in adolescence?


| | |
|---|---|
| Principal Investigator: | Professor Sarah-Jayne Blakemore |
| Postdoctoral Researcher: | Dr Lisa J. Knoll |
| Research Assistant: | Mr Ashok Sakhardande |
| PhD Student: | Ms Delia Fuhrmann |

Contact: Doctor Lisa Knoll

*email:*
l.knoll@ucl.ac.uk

*address:*
UCL Institute of Cognitive Neuroscience
17 Queen Square
London WC1N 3AZ


## Executive Summary


A perennial question in education is when to teach what. Education policies often focus on early education as a key window for learning [1], but in the current experimental study, we wanted to investigate the possibility that cognitive skills related to mathematics performance in schools are more efficiently acquired later in development. In our study, whose key findings were published in *Psychological Science* [2], 633 adolescents and adults aged 11-33 years were trained in different cognitive tasks for up to 20 days. Participants were assigned at random to one of three training groups. One training group was trained to discriminate small from large *numerosities*, number of items there are in a given set, an important skill as we often have to compare and judge quantities in our everyday life. The second group was trained in *relational reasoning*, which is the ability to detect abstract relationships between groups of items and is related to fluid intelligence. Both skills are relevant to education and correlate with mathematics. The third group was trained in *face perception*, which is not related to mathematics. This group served as a control group. Participants were tested on a range of cognitive tasks before and after the training, and several months after training had ceased. Training in the numerosity discrimination task yielded some improvement in performance, but only in late adolescence and adulthood (~15-33 years). All age groups improved their performance when trained in relational reasoning, but older adolescents and adults showed the highest training benefits. Face processing showed limited training effects and no differences between age groups. These findings suggest that skills relating to mathematics are more efficiently learned in late adolescence and adulthood than earlier in adolescence. These findings highlight the relevance of this late developmental stage for education, and challenge the assumption that 'earlier is always better' for learning.

## Background

Education policy tends to emphasise the importance of investing in early childhood intervention. This argument is partly based on well-established economics accounts of the added value of early childhood intervention [1]. However, there is a tension between the assumption that earlier is always better and the recent findings that the human brain continues to develop throughout childhood, adolescence and into early adulthood.

Adolescence is the period of life between puberty and relative independence [3]. Over the past two decades, research has shown that several brain regions in humans undergo protracted structural and functional development across adolescence [4, 5]. Regions that undergo particularly substantial development during adolescence include the prefrontal and parietal cortex. These regions are involved in a variety of higher cognitive skills relevant to maths education, including reasoning and numerical skills [5-7]. There is evidence that each of these cognitive skills undergoes development during adolescence [6, 8, 9]. However, little is known about when during adolescence these skills are most efficiently learned.

Here, we trained performance of three cognitive skills: numerosity discrimination, relational reasoning and face perception. Numerosity discrimination is the ability to discriminate small from large numerosities, and relational reasoning is the ability to detect abstract relationships between groups of items. These cognitive skills were chosen because they involve brain regions that undergo development in adolescence and because relational reasoning and numerosity discrimination performance improves during adolescence. Therefore, these skills might be expected to be particularly trainable in adolescence. In addition, both skills are relevant to education. They are correlated with mathematics performance [10], and relational reasoning is also related to fluid intelligence, a significant predictor of educational outcomes [11].

Face perception, the ability to identify changes in faces and facial features, was included as the control training task. Face perception also improves during adolescence and may be susceptible to training, but it relies on different cognitive processes and neural circuits than those involved in numerosity discrimination and relational reasoning [12, 13]. We thus reasoned that there would be no transfer from face perception training to numerosity discrimination and relational reasoning performance, or vice versa.

The goal of the current training study was to investigate when in adolescence certain cognitive skills are best trained. Previous studies have investigated cognitive training mainly in children and adults. Here, we compared training effects between four age groups: 186 younger adolescents (11.27-13.38 years); 186 mid-adolescents (13.39-15.89 years); 186 older adolescents (15.90-18.00 years); and 105 adults (18.01-33.15 years). We investigated three central hypotheses: (a) *General training effects:* Training would improve performance on the trained task only; (b) *Age-dependent training effects:* Performance on the trained task would improve after training within some or all age groups and the strength of improvement would differ between age groups; (c) *Transfer effects*: Training effects might generalise to performance on a non-trained task that involves similar cognitive processes. Specifically, training in relational reasoning might lead to improvements in performance on an untrained working memory task [14], and training in face perception might lead to improvements in performance on an untrained face memory task [15].

## Methods

Recruitment: Recruitment targeted two groups of volunteers: students in Years 7-13 (aged 11-18) and adults (aged 19-33). We contacted over 45 schools directly and a number of external individuals (e.g. UCL Partners and people working for local authorities) helped contact schools on our behalf. Of these we tested in 16 schools located in and around London, 13 of which were state schools. Adults were recruited through UCL participant pools and tested in groups in UCL computer rooms.

Testing and training: Participants in our study were tested at three time points: at baseline, after training and at follow-up (Fig.1).

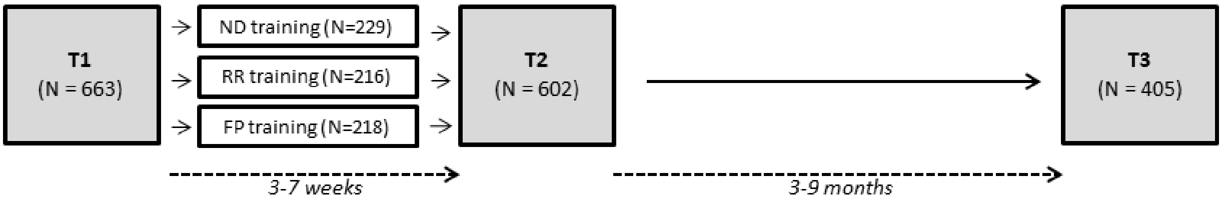


***Fig. 1.*** *Timeline of the study and number of participants at each stage. T1 = baseline testing, T2 = testing after training, T3 = follow-up testing, ND: numerosity discrimination, RR: relational reasoning, FP: face perception, N: number of participants.*

After baseline testing, participants were asked to complete 20 sessions of 10 minutes online training on one of the three training tasks (numerosity discrimination, relational reasoning or face perception). Testing and training was carried out on an online platform developed with a software partner (cauldron.sc). The training platform was designed to resemble school-based learning: testing was carried out in groups in the classroom and the training programme was comparable to homework. Participants trained for 10min a day, five days a week and up 20 days in total. The training was designed to be motivating by providing positive feedback, such as flashing stars, after every correct response. Motivational phrases (e.g. “awesome!”, “three in a row!”) were shown intermittently. To incentivise training further, participants received virtual trophies. Before each training session, participants were asked to select a trophy chest (bronze, silver or gold), and after the session they could open the chest to find a trophy that would be displayed in their online trophy cabinet. Participants were able to track the number of training sessions they had completed by viewing their trophy cabinet. Participants were reminded about training by automated daily e-mails and additional e-mail reminders sent by the research team, and teachers were asked to remind adolescent participants to train.

Participants were tested on five tasks at the three testing time points: numerosity discrimination, relational reasoning, face perception, face memory and backwards digit span. Numerosity discrimination and relational reasoning were trained because they were expected to be amenable to training during adolescence. These skills are considered important as they are related to mathematics performance in schools.

Face perception was trained as a control task not related to mathematics. The face memory and backward digit span working memory tasks were not trained and included only during testing to investigate whether the training transferred to related - but non-trained - skills. See Fig.2.

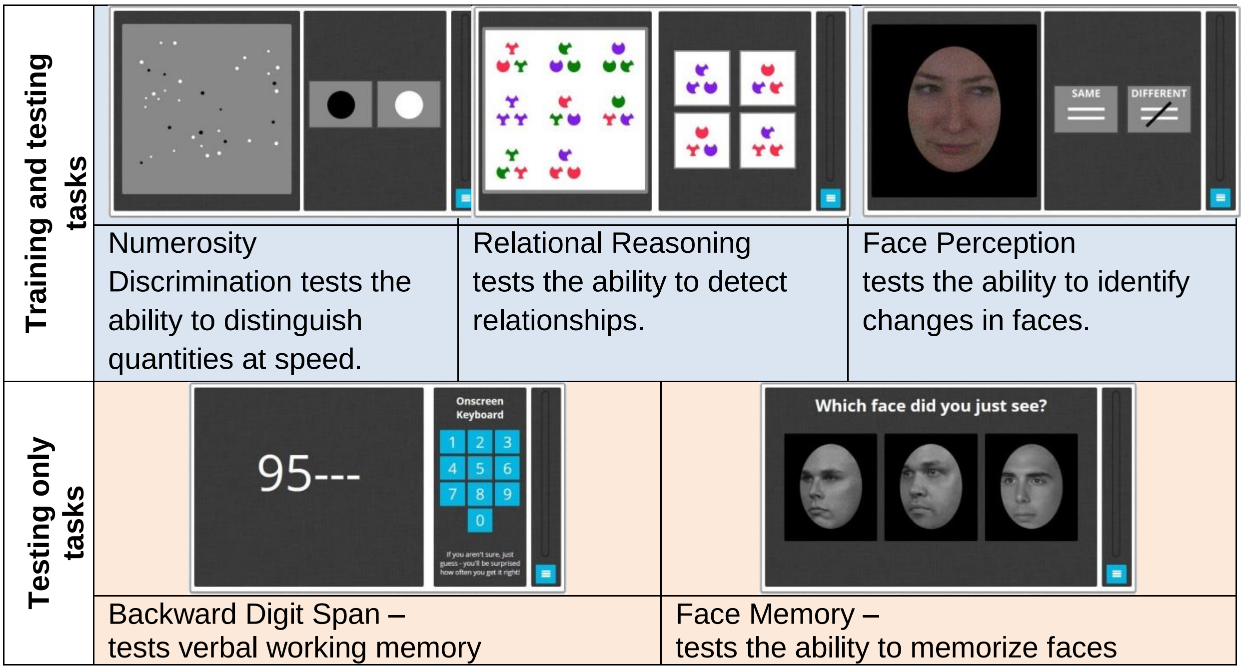


***Fig. 2.*** *Screenshots and descriptions of each of the five cognitive tasks used in the three testing sessions.*

For students and adults, each testing group consisted of between 10 and 50 students. Data from 821 participants were collected in total. Data from 123 students were excluded because parental consent was not provided. Participants' data were also excluded if they reported a diagnosis of developmental conditions, including ADHD, autism, dyscalculia, dyslexia and epilepsy (N = 34) or if they were not present during testing at T1 (N = 1). The final sample at T1included data from 663 participants (398 females) and was divided into four age groups: 186 younger adolescents (11.27-13.38 years); 186 mid-adolescents (13.39-15.89 years); 186 older adolescents (15.90-18.00 years); 105 adults (18.01-33.15 years).

## Results

We found different patterns of learning between the three trained cognitive skills. Overall, participants who were trained in numerosity discrimination improved their numerosity discrimination skills more than participants trained in one of the other tasks. However, these effects were age-dependent: only older adolescents and adults significantly improved their performance after training, and adults improved significantly more than younger adolescents (Fig. 3).

Relational reasoning training improved relational reasoning performance compared to training in other tasks. This training effect was observed in all age groups: relational reasoning training improved relational reasoning performance throughout adolescence and adulthood. The effects survived six-months without further training. Between-age group comparisons showed that the benefit from relational reasoning training increased from mid- to late adolescence, after which no further benefit was found in adulthood. Parallel to the pattern observed in the numerosity discrimination task, older adolescents and adults showed a significantly higher improvement in relational reasoning compared with younger age groups (Fig. 3).

Participants who were trained on the face perception control task showed improvements in identifying changes in faces and facial features compared to participants trained in numerosity discrimination only. There was no difference in training effects between age groups (Fig. 3).

There was no evidence of transfer from numerosity discrimination or relational reasoning training to a backward digit span working memory performance or from face perception training to face memory performance.

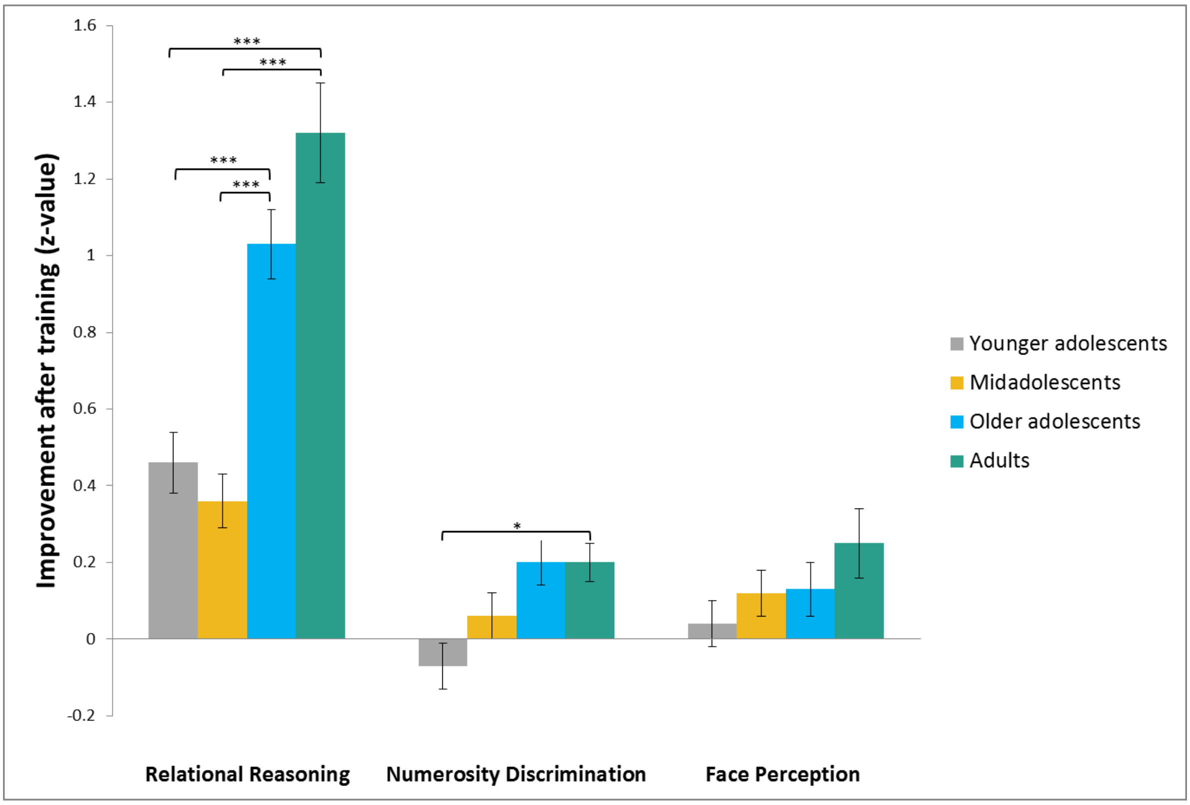


***Fig. 3.*** *Improvement after training (z-scores) for all age groups (186 younger adolescents (11.27-13.38 years); 186 mid-adolescents (13.39-15.89 years); 186 older adolescents (15.90-18.00 years); and 105 adults (18.01-33.15 years) and training groups on their trained task. Asterisks indicate a significant difference in improvement between age groups.*
** $p < 0.05$. ** $p < .005$, *** $p < .001$*

## Conclusion

We found that complex cognitive skills relevant to mathematics education, particularly relational reasoning, show larger training effects in late adolescence than earlier in adolescence. These findings highlight the importance of late adolescence for education and, in contrast to the common assumption that ‘earlier is better’ for learning, the results highlight late adolescence and adulthood as a potential window of opportunity for educational interventions.

## Recommendations for Policy and Practise

1. This study, as well as work from other research groups [6, 16, 17], shows that relational reasoning, which is often a part of IQ tests, develops over the course of adolescence and is highly susceptible to training. This highlights that IQ is not necessarily a stable characteristic of the individual and calls into question the use of IQ tests for entrance exams in schools.
2. Education policy tends to focus on early life interventions, a practise that is partly based on the economics of early-life investment [1]. While early education is undoubtedly important for many cognitive skills such as visual or language development [18, 19], this study shows that certain complex cognitive skills related to mathematics may be best trained relatively late in development, from 15 onwards. This calls into question the idea that earlier is always better for learning. The results imply that it is possible to teach certain cognitive skills later in adolescence.
3. There was no evidence of transfer from cognitive training to untrained cognitive tasks. Training on relational reasoning, for example, had no effect on the other skills tested, including working memory. This mirrors much of the cognitive training literature, which shows that cognitive training often shows little generalizability [20]. To use cognitive training as a tool for education or interventions, transfer is important. The aim of practitioners is not only to improve performance on specific tasks but to train generalizable skills. The current implementations of cognitive training may not yet be ready for use in practise.

## Questions for Future Research

- Which other cognitive and/or social-emotional skills are best trained in late adolescence?
- What are the mechanisms for enhanced learning in late adolescence and adulthood? Is there evidence of increased neural plasticity?
- Who benefits most from training? People who start out with relatively high performance or people who start with relatively low performance?
- How can transfer from cognitive training to non-trained tasks be optimized? Could broader, more intensive training paradigms show higher transfer?
- Is cognitive training in schools useful, is it feasible and how should it be implemented?

## Acknowledgements

We gratefully acknowledge the generous funding of this project by the Nuffield Foundation. The Nuffield Foundation is an endowed charitable trust that aims to improve social well-being in the widest sense. It funds research and innovation in education and social policy and also works to build capacity in education, science and social science research. The Nuffield Foundation has funded this project, but the views expressed are those of the authors and not necessarily those of the Foundation. More information is available at [www.nuffieldfoundation.org](http://www.nuffieldfoundation.org)

## References


1. Heckman, J.J. (2006) Skill formation and the economics of investing in disadvantaged children. Science 312 (5782), 1900-1902.
2. Knoll, L.J. et al. (2016) A window of opportunity for cognitive training in late adolescence. manuscript under review.
3. Steinberg, L. and Morris, A.S. (2001) Adolescent development. Annual Review of Psychology 52, 83-110.
4. Tamnes, C.K. et al. (2010) Brain maturation in adolescence and young adulthood: Regional age-related changes in cortical thickness and white matter volume and microstructure. Cerebral Cortex 20 (3), 534-548.
5. Blakemore, S.J. and Robbins, T.W. (2012) Decision-making in the adolescent brain. Nature Neuroscience 15 (9), 1184-1191.
6. Dumontheil, I. et al. (2010) Development of relational reasoning during adolescence. Developmental Science 13 (6), F15-24.
7. Houdé, O. et al. (2010) Mapping numerical processing, reading, and executive functions in the developing brain: an fMRI meta-analysis of 52 studies including 842 children. Developmental Science 13, 876-885.
8. Crone, E.A. et al. (2009) Neurocognitive development of relational reasoning. Developmental Science 12 (1), 55-66.
9. Halberda, J. and Feigenson, L. (2008) Developmental change in the acuity of the "Number Sense": The Approximate Number System in 3-, 4-, 5-, and 6-year-olds and adults. Developmental Psychology 44 (5), 1457-1465.
10. Halberda, J. et al. (2012) Number sense across the lifespan as revealed by a massive Internet-based sample. Proceedings of the National Academy of Sciences 109 (28), 11116-11120.
11. Chuderski, A. (2014) The relational integration task explains fluid reasoning above and beyond other working memory tasks. Mem Cognit 42 (3), 448-63.
12. Cohen Kadosh, K. et al. (2013) Differential face-network adaptation in children, adolescents and adults. Neuroimage 69, 11-20.
13. Cohen Kadosh, K. et al. (2013) Effects of age, task performance, and structural brain development on face processing. Cerebral Cortex 23 (7), 1630-1642.
14. Klingberg, T. (2010) Training and plasticity of working memory. Trends in Cognitive Science 14 (7), 317-24.
15. Dolzycka, D. et al. (2014) Can training enhance face cognition abilities in middle-aged adults? PloS one 9 (3), e90249.
16. Mackey, A.P., Behavioral and neural effects of reasoning training, University of California Berkeley, Berkeley, CA, 2012.
17. Mackey, A.P. et al. (2011) Differential effects of reasoning and speed training in children. Developmental Science 14 (3), 582-590.
18. Hubel, D.H. and Wiesel, T.N. (1970) The period of susceptibility to the physiological effects of unilateral eye closure in kittens. The Journal of Physiology 206 (2), 419-436.
19. Kuhl, P.K. (2010) Brain mechanisms in early language acquisition. Neuron 67 (5), 713-27.
20. Owen, A.M. et al. (2010) Putting brain training to the test. Nature 465 (7299), 775-8.