A window of opportunity: a neuroscience perspective on the gender stereotyping of science in the early years

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Abstract

21st century neuroscience research has revealed the link between key aspects of brain development and the very early emergence of social awareness in young children. This includes evidence of gender detection and processing in children as young as two years old, followed over the next three to four years by gender alignment and gender compliance. Increasing focus on the effects of gender stereotyping in these early years has led to consideration of the role of primary education in many aspects of gender socialisation and their potentially limiting consequences.

One such issue is the claim that the under-representation of women in STEM (Science, Technology, Engineering and Mathematics) is linked to the effects of certain gendered stereotypes about science and scientists, with evidence that the origins of gender imbalances in science subjects may be found in very early developmental experiences and expectations.

This paper outlines a temporal framework linking brain development to key stages of gender processing and of children's endorsement of gender stereotypes in science.

Keywords: Gender stereotypes, brain development, STEM (Science, Technology, Engineering, Mathematics), gender awareness, science stereotypes

Introduction

Worldwide, technological innovations mean that we have a greatly increased need for specialists in STEM (Science, Technology, Engineering, Mathematics) subjects. This demand is not being matched by supply (President's Council of Advisors on Science and Technology, 2012). The problem is compounded by the fact that women, 49.7% of the world's population, despite clear evidence of aptitude and ability for science subjects, are not choosing to study STEM subjects, are not being recruited into the STEM workforce, and are not staying in the STEM workplace. Globally, women account for less than a third (29.3%) of those employed in scientific research and development (Unesco, 2019).

Why don't women do science? Historically, an early explanation suggested that women were 'constitutionally' unsuited to the rigours of science education and practice and/or that they were innately deficient in key brain-based cognitive skills. Decades of research have, as yet, been unable to establish a consistent basis for such claims. Additionally, sophisticated performance measures have indicated that there are few or no sex differences in key measures of science-based skills, or that apparent innate sex differences are actually related to stereotype-driven differences in relevant learning or training opportunities. But the fact remains that girls *don't* do science, are *choosing* not to do science, as the statistics above indicate. Attempts to address this problem in the educational arena have commonly focused on secondary schools (WISE, Institute of Physics), but research indicates that determinants of this eventual choice can be found very early on in girls' educational journeys, involving key phases of brain development linked to the emergence of stereotyped beliefs and behaviour.

Gender[1] gaps? Blame the brain

A continuing challenge to any attempts to address gender stereotypes (in any arena, at any age) is the deeply embedded belief that gender gaps (in any arena, at any age) are actually a measure of innate processes, predetermined, inevitable and invariant (Eagly & Wood, 2013). Social and cultural differences have been afforded limited power in explanatory models of gender gaps; indeed, the more traditional biological determinist views suggest that such differences were actually a reflection of biological factors. In science, for example, the 'essentialist' view suggested that female brains did not endow their owners with the appropriate portfolio of cognitive skills or personal attributes; access to education was not considered relevant (Schiebinger, 1991).

This approach is dramatically undermined by the lack of any consistent evidence that the brains of women and men, of girls and boys, are, in fact, different. Despite decades of research into these alleged differences, it is clear that female and male brains are more similar than they are different, and that explanations of gender gaps (in any arena, at any age) need to look beyond simplistic, unidirectional models based on sex-determined differences in the brain (Rippon, 2019).

Developments in 21st century neuroscience now afford a more powerful role for *external* factors in determining brain development and function, by demonstrating that socially or culturally determined rules, experiences and expectations can bring about significant changes in the brain.

BrainWorks – the three Ps: predictive, plasticity and permeability (Rippon, 2020)

It is now known that brains function rather like '***predictive*** texters', proactively extracting patterns and rules of behaviour from the outside world to guide appropriate or successful behaviour (Friston *et al*, 2014). These can include social rules, such as an understanding or prediction of how people might react in a particular situation, or the characteristics associated with particular identities (including your own) (Frith & Frith, 2010; Tamir & Thornton, 2018). This predictive coding process in the brain is supported by intricately connected networks or circuits, formed during key periods of brain development, especially the early years (Gao *et al*, 2017). These periods of maximal connectivity development in the brain are therefore associated with the emergence of high levels of rule-gathering behaviour, including social behaviour (Gotts *et al*, 2012).

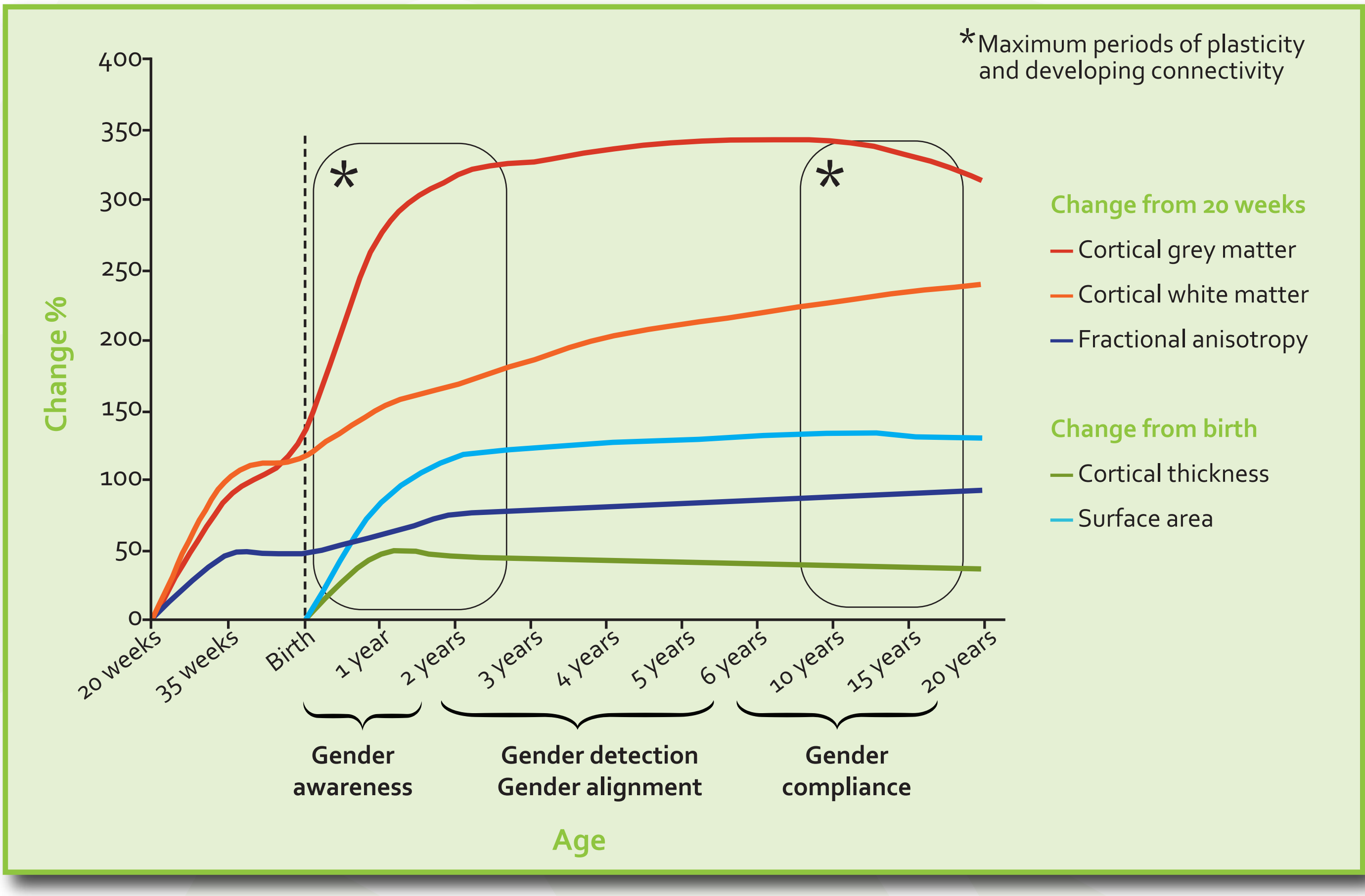
Similarly, these are periods of maximal ***plasticity***, of variation in key structural and functional development associated with variations in learning opportunities and experiences. An early focus was on marked developmental deficits associated with extremes of, for example, deprivation or disease (Chugani *et al*, 2001). But recent work has identified more subtle brain-based differences in typical development linked to early experience, such as opportunities for second language learning. Just as there are sensitive periods in sensory or motor development, it would appear that there are similar optimal periods associated with the benefits of more general, cultural opportunities (DeHaene, 2020).

In adults, the brain's ***permeability*** to social context, the attitudes and expectations associated with human social behaviour, have also been identified. Brain-imaging studies have shown that negative stereotyped beliefs associated with specific abilities (for example, females are poor at spatial thinking) are associated with lower levels of performance and altered brain activation (Wraga *et al*, 2007). In children, a similar effect has been demonstrated with specific negative self-beliefs, such as maths anxiety (Young *et al*, 2012).

This newer understanding of the interactive relationship between brains and external social factors can provide a framework for understanding the role of gender stereotypes in establishing (and maintaining) gendered patterns of behaviour in young children. Exposure of an exuberantly rule-gathering, experience-dependent brain to a firmly rule-based system of experiences and expectations provides a fertile substrate for the formation of potentially lifelong patterns of beliefs and behaviours.

[1]There is considerable debate concerning the appropriate use of the term 'gender' as opposed to 'sex'. The former is generally considered to be a cultural construct, referring to social norms and roles, whereas the latter is taken to refer to biologically determined characteristics of females and males. Although the entangled nature of these two concepts is acknowledged, the term 'gender' will be used here to refer to the processes being examined.

Figure 1. Figure 1 shows a mapping of periods of brain structural development against the emergence of key stages of gender processing (adapted with permission from Gilmore, J.H., Knickmeyer, R.C. and Gao, W. (2018), 'Imaging structural and functional brain development in early childhood', *Nature Reviews Neuroscience*, **19,** (3), p.123. Guilford Press).



Applying this model to the emergence of gender stereotypes with respect to science and scientists, specifically of stereotypes as to who does and does not do science, could identify key time windows in the origins of this problematic bias.

Brain development and social processing

As a result of 21st century developments in imaging brain development in babies and young children, we now have a detailed window into the nature and timescale of early structural changes in the brain. These can then be mapped against a timetable of behavioural changes/phases of interest, to identify potentially sensitive periods in the establishment of such behaviours, where identified relevant factors could be maximally effective.

Early on, links between early brain development and developing infant behaviour focused on emerging cognitive skills such as perception and language. More recently, attention has turned to early social skills, such as the differential recognition of a caregiver's face or voice or an understanding of different types of affective information (Simion & Giorgio, 2015). Accumulating evidence indicates that infants and young children are capable of highly sophisticated social processing, demonstrated by evidence of activation in key areas of the social brain, previously assumed to be functionally silent in very young children (Grossman, 2013). It is now known that such social processing can include, from a very young age, an awareness of gender differences and, only slightly later, their social significance (Martin & Ruble, 2004).

Gender processing: key stages

a. Gender awareness

With respect to early signs of gender awareness, children as young as six months have been shown to register normal gender differentiators, responding differently to 'gender inconsistencies' such as a high-pitched voice matched with a male face (Poulin-Dubois *et al*, 1994). By two years old, awareness of more socialised inconsistencies has been demonstrated, with toddlers' attention significantly captured by, for example, images of men putting on lipstick (Poulin-Dubois *et al,* 2002). Similarly, toy choice studies have shown that it is at this age that sex differences in response to gendered colour coding become evident, with boys actively rejecting pink toys (LoBue & DeLoache, 2011).

b. Gender rules – identification and alignment

By two years old, gender cues have been registered and are starting to affect behaviour (Martin & Ruble, 2004). This marks the onset of the 'gender detection' phase, linked to the emergence of gender identity, where young children appear to seek out ways of appropriately allocating a gender to whatever they find in their world, be it other children, adults, clothes, toys, games. This parallels the early stages of predictive coding in brain development as outlined above, where emerging patterns of connectivity support the development of rule-based perception and cognition.

The causal power of stereotyped gender cues in children's gender questing activity has been demonstrated in 3-5 year-olds by observing the effect of gender coding on previously neutral objects. Requested to sort objects such as melon ballers or garlic presses that had been painted pink or blue into 'for boys' or 'for girls' categories, the children firmly followed the pink-blue divide in their choices. Modelling had a similar effect – having watched videos showing either males or females using a range of neutral objects, children again sorted these objects according to who used the items, rather than what they were used for (Weisgram *et al,* 2014).

Gender detection is also commonly associated with gender alignment and can be a time of quite fierce gender policing around, for example, the dressing-up box. Girls in particular can demonstrate firm views as to what is appropriate for them to wear – labelled as the 'pink frilly dress' phenomenon (Halim *et al,* 2014). It is also a phase where naïve logic linked to occupational stereotypes can be observed, commonly reflecting everyday experiences (my bus driver is a man, so only men can be bus drivers), or in response to the kind of modelling effects demonstrated with toys; gender bias in images of males or females occupying different roles can lead to 'stereotype endorsement' of the 'women are nurses, men are scientists' kind. Such beliefs in the gender divide in adult occupations have been illustrated at this age by examining children's drawings of, for example, fighter pilots or nannies, and registering their astonishment when presented with counter-stereotypical examples (Redraw the Balance, 2016).

Research has shown that occupational stereotypes about scientists are a major part of the gender lexicon acquired by early years children. For example, the draw-a-scientist test has been a popular source of demonstrating clearly biased stereotypical views among young children (Finson, 2002). Such beliefs may be compounded by science educational resources themselves. A recent visual content analysis of over two thousand online primary science resources showed that, with respect to the depiction of science professionals, 75% of images were of males (Kerkhoven *et al,* 2016). In children's science books, women are significantly under-represented, particularly in physics and maths (Caldwell & Wilbrahim, 2018).

Stereotypical endorsement of different occupations is associated with the next stage of gender compliance, of children linking their gendered self-identity to a gender-related social stereotype in accordance with models such as Gender Schema Theory (Starr & Zurbriggen, 2017) or Social Role Theory (Eagly & Wood, 2016). By the age of about five and a half to six years onwards, there is evidence that children have categorised different occupations as female or male and align their future ambitions and expectations accordingly (Martin & Ruble, 2004).

This gender alignment effect divide can also be shown in children's views of their own relevant abilities and skill sets. By the age of seven, girls have been shown to be significantly less likely to support the notion that girls (i.e. their own sex) are 'really really clever' (Bian *et al,* 2017). Linked to the notion that science is only done by 'really really clever people', the stereotype of science as 'not for girls' can swiftly be established. Girls as young as 6-7 years old believe that maths is a 'boy thing' and that they would therefore be unlikely, in the future, to engage with maths or maths-related activities (Cvencek *et al,* 2011).

c. Gendered experiences – XX/XY or X-box?
Toys have proved to be a powerful battleground in research into explanations of emerging gender differences in children. The apparently fixed preferences among girls for dolls, pink paraphernalia and fantasy worlds, and among boys for mechanical objects, construction kits and guns, have been claimed as supporting evidence for both the 'nature' and the 'nurture' camp. The former claim that this gender bias is related to innately-determined and evolutionarily significant caring or nurturing roles for girls and constructionist, competitive roles for boys; the latter nominate socially-determined role stereotyping and/or market-driven forces firmly steering previously neutrally-minded children down a pink-blue divide (Fine & Rush, 2018). A detailed examination of the evidence in support of either side is beyond the scope of this paper, but the relevance of investigating a gendered toy divide in an understanding of science stereotypes is to note the differential training opportunities and experiences that play can give young children.

Cognitive neuroscience studies have shown that experience with games such as Tetris or Super Mario can not only improve spatial performance in young adolescents, but also alter associated brain structure and function (Haier *et al*, 2009; Kuhn *et al*, 2014). And apparent sex differences in spatial ability have been shown, in reality, to be a function of spatial experience with childhood toys and hobbies such as videogame playing (Terlecki & Newcombe, 2005). Given that spatial ability has been identified as a core competency in science (Wai *et al*, 2009), any gender bias in experience of or access to relevant 'training' opportunities, for example via play, can impact on the development of spatial skills. Using the Preschool Occupations, Activities and Traits scale in 4-5 year-olds, researchers showed that, even at this young age, there was evidence of stereotyped beliefs that boys would be more likely to play with LEGO blocks and would be better at using them (Shenouda & Danovitch, 2014).

d. Gendered attitudes – the not-so hidden truths
Noting the differential values associated with the different genders is also part of the rule-gathering activities of developing brains. The different attitudes and expectations, both conscious and unconscious, of adults about what is appropriate for, or expected of, girls or boys has been well documented. And children show a very early awareness of this. In a small-scale study, 3-5 year-old girls and boys were asked to identify toys as 'for girls' and 'for boys' and then asked which toys their parents would like them to play with (Freeman, 2007). There was clear agreement among the children as to which toys were for boys or for girls and, more significantly, of the level of parental disapproval of playing with cross-gendered toys – for example, only 9% of 5 year-old boys thought that their fathers would approve of them playing with a doll or a tea set. (A twist to this study was that the parents of these children were also being asked about their agreement or disagreement with gender stereotypes. One finding was that between 60% and 90% of parents indicated their disapproval of the gendering of toys or activities.)

With respect to parental attitudes about gender and science, endorsement of science as 'for boys' is also well documented (Mulvey & Irvine, 2018). More negatively, specific identification of science as 'not for girls' is also evident (Archer *et al*, 2013). A parallel thread to this is the relationship between the STEM-excluding consequences of maths anxiety, more common in girls, and the attitudes to maths found in parents, especially mothers (Gunderson *et al*, 2012).

It has also been shown that, in the early years, teachers' stereotyped beliefs can indirectly contribute to gender gaps in engagement with science. A longitudinal study examined the effects of teacher estimates of science ability at primary school level. Evidence of gender bias was clear, with teachers over-marking boys and under-marking girls. This bias score was then found to have a significant causal effect on subsequent choice of science subjects in later educational stages (Lavy & Sand, 2015).

Challenging stereotypes – the role of early years and primary science?

21st century developmental cognitive neuroscience indicates that early childhood is a key developmental window in which stereotypical beliefs and behaviours become established, in parallel with a heightened period of plasticity and connectivity in brain development. This underpins key processes in social behaviour, such as responsiveness to coded social rules, self-categorisation according to perceived social norms, and avoidance of stereotypically proscribed activities or events. An awareness of the differential values attached to stereotypically distinct groups or behaviours is also evident in these early years. In just the same way that the self-organising experience-dependent nature of the developing brain makes it vulnerable to gender stereotyping, its very plasticity and mouldability in the early years offers the opportunity to counteract the negative effects of such stereotyping. So, primary education offers an effective forum in counteracting the development of negative sets of beliefs about who can and can't do science, and why. Challenging the *status quo* and the rules, offering counter-stereotypical examples and experiences, and carefully monitoring negative attitudes can all have a moderating effect and prevent stereotypes from becoming fixed and unchangeable (Olsson & Martiny, 2018). Hopefully this can set firm foundations for later initiatives to encourage greater engagement with science.

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