OLIVER BRADDICK

Oliver John Braddick

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by

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Oliver Braddick made major contributions to our understanding of the nature and development of human vision, with a particular focus on perception of depth and motion. His elegant experimental designs and theoretical insights have had an enduring impact on the field of visual perception. In a long and productive collaboration with his wife, Janette Atkinson, he developed ingenious new approaches to the study of visual development in babies, which extended to clinical investigations of visual consequences of diseases affecting the eye and brain. He also was an exemplary Professor and Head of Department at two of the premier experimental psychology departments in the UK, University College London (1998–2001) and Oxford (2001–2011).

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Oliver Braddick

Childhood

Oliver Braddick was the only child of Henry John James Braddick ('Jimmy'), a reader in physics at Manchester University, who had worked under both Ernest Rutherford and Patrick Blackett, and Edith Muriel ('Midge'), a teacher who was also a gifted artist. Braddick had a happy childhood in Didsbury, where his parents, keen members of the Fabian Society, would take him hiking in the local countryside, and on barge holidays on the canals. Under his mother's influence he flourished as an amateur artist and developed a life-long interest in photography. His mother taught modern languages and Braddick soon became fluent in German and French.

Education

Braddick attended school first at the local primary in Beaver Road and subsequently at The Manchester Grammar School, which prided itself on its teaching of maths, physics and chemistry. The school identified his outstanding ability and decided he should do only the minimum number of O-level (ordinary level) exams in order to focus on A-levels (advanced) in double maths, physics and chemistry, equipping him to obtain a scholarship to read Natural Sciences at Trinity College, Cambridge just before the age of 17.

Braddick initially intended to follow in his father's footsteps at Trinity as a physicist, but the field of psychology must be grateful to the Cambridge Natural Sciences Tripos, which required him to take two other sciences. Chemistry was an obvious choice, but after that he had to decide between Mineralogy or Experimental Psychology. Once Braddick had attended a set of demonstrations in the psychology department by the charismatic Richard Gregory he was hooked. The study of visual perception requires a rigorous understanding of physics and biology in attempting to account for the way stimuli that fall on the retina are perceived by the brain as objects with properties such as depth, colour, edges and movement. At this time, Gregory would have been finalising his renowned popular book *Eye and Brain* (1966), which focused on the potential of visual illusions to throw light on this translation, by studying cases where there is a mismatch between what we perceive and what is 'out there' in the world. Braddick decided that vision was what interested him, and after obtaining his BA in 1965, he enlisted as a doctoral student in 1968, supervised by Gregory. In this pre-computer age, Gregory had a knack for creating compelling demonstrations of visual phenomena, one of which used a railway track to present stimuli that could move towards or away from the viewer. This may have stimulated Braddick's interest in the topic of his thesis, which was binocular vision. By cleverly varying characteristics of separation and orientation of stimuli presented to the left and right eyes, Braddick could show there could be dissociation between stereopsis (seeing depth) and binocular single vision (seeing a single object despite viewing with two eyes). A good overview of this early work can be found in Braddick (1979).

Early academic career

After a one-year postdoc at the laboratory of Lorrin Riggs at Brown University in the USA, Braddick returned to Cambridge as a university demonstrator, subsequently being promoted to lecturer and then reader. Between 1969 and 1972, he combined his teaching activities with a research fellowship at Trinity College.

These were exciting times to be a vision researcher in Cambridge. The University had created the Kenneth Craik Laboratory with the aim of bringing together vision researchers from physiology and psychology. The, almost exclusively male, environment included some of the great luminaries of the field, although the hoped-for integration of physiology and psychology could be challenging. Physiologist Horace Barlow believed that to understand vision, one needed to derive computational principles from biological processes, identifying neural units with selective tuning for visual properties such as orientation or motion. Barlow focused on low-level summation and inhibition in the retina, as well as higher-level feature detection ('bug' detectors). In contrast, Richard Gregory regarded visual perception as a problem-solving process: our pre-existing knowledge of the world is used in a top-down fashion to interpret sensory input as evidence for an external object or event. Braddick benefited from exposure to these diverse influences, and aimed to link top-down and bottom-up processes in vision, stimulated by the work of physiologists Fergus Campbell and Colin Blakemore, as well as Barlow.

Gregory departed for Edinburgh in 1967, but the psychology department remained strong in neuropsychology and perception, with the influence of colourful characters such as 'old C' Grindley, one of the founders of the Experimental Psychology Society. He would give popular demonstrations of experiments using a tachistoscope – in those days a standard piece of equipment, used to present precisely timed stimuli. The eminent neuropsychologist Oliver Zangwill was Professor of Experimental Psychology and Head of Department; he had played a major role in recruiting Braddick. Overall, Cambridge in the 1960s-1970s was a magnet for academic visitors interested in vision science, including a memorable visit by Edwin Land, inventor of polaroid film, in a limousine.

Braddick developed an interest in perceptual learning, the notion that experience of particular stimuli can influence how they are perceived. In an early paper that remains highly cited to this day,[1] V.S. Ramachandran and Braddick demonstrated this point using random line stereograms; these are random patterns of lines that vary in orientation, presented to left and right eyes, and identical on the two sides except for a proportion of the dots that are displaced horizontally in one image. When viewed in a stereoscope, the images fuse to give an impression of depth. Ramachandran and Braddick showed how changing the orientation of the elements in the stereogram affected the time it took for naïve observers to learn to perceive depth. This kind of neat experiment, where details of experimental stimuli were manipulated to throw light on the basis of perceptual phenomena, characterised Braddick's meticulous approach. His early papers using stereograms to study the processes of masking[2] and visual motion[3] remain as core sources for vision researchers in current times. His paper on short-range apparent motion was particularly influential; he defined the conditions under which this phenomenon occurred when a stimulus was presented to the same eye repeatedly over a precisely timed interval.

Early work on infant vision

In the early 1970s, Braddick began a life-long collaboration with his future wife, Janette Atkinson, who was then a PhD student supervised by Paul Whittle (and one of the only female graduate students in the Cambridge Department), studying cortical mechanisms using afterimages. Their shared interests and complementary skills made a powerful combination, and from this point on they worked so closely together that it is not possible to separate their independent contributions on their joint projects. The topic that they focused on and made their own was the study of visual development in human infants. This was a bold step. Up to that point, most research on vision had either involved asking adult human observers to report what they could see, or had relied on presenting visual stimuli while recording responses from brain cells in animals such as rats or cats. Babies presented problems for both methods, so the question was how on earth could one obtain reliable data from such young humans, without invading their brains or requiring them to speak.

Despite these difficulties, it was clear that the study of infants had enormous potential to throw light on the extent to which experience shaped perception – a question that was starting to attract the interest of Braddick's colleagues in the physiology department. Notably, Colin Blakemore, an exact contemporary of Braddick, was doing exciting studies that showed experience-dependent plasticity of the visual system in cats.

[1] Ramachandran & Braddick (1973).
[2] Braddick (1973).
[3] Braddick (1974).

Around this time, developmental psychologists had been making progress with methods that allowed one to infer the ability of babies to distinguish stimuli by their responses (e.g. by looking preferentially at one visual stimulus rather than another). An encounter with visitor Alan Hein, led Braddick and Atkinson to learn about the work of Davida Teller, who had just started to modify the preferential looking method to measure visual acuity in infants. This was called 'forced-choice preferential looking'. The infant was shown two images, side by side, and an observer (out of sight of the infant, looking through a central peep hole) observed the infant's eyes and head movements. At the end of a timed test period, the observer had to choose which side the infant looked at preferentially. This way, one could demonstrate whether infants are above chance at discriminating between the images on the two sides. Using this approach, Braddick and Atkinson developed an experimental method that used spatial frequency analysis to assess visual sensitivity.

In these studies the infant is seated in front of two displays, matched in average luminance (see Figure 1). One screen shows a uniform grey stimulus, while the other shows a grating (striped pattern), the stripes varying in shade of grey; the side of the grating pattern on the left or right screen is varied at random across trials, and the expectation is that if the grating is detectable, the infant will look more at it (from the general principle that infants prefer to look at something patterned rather than a blank screen).

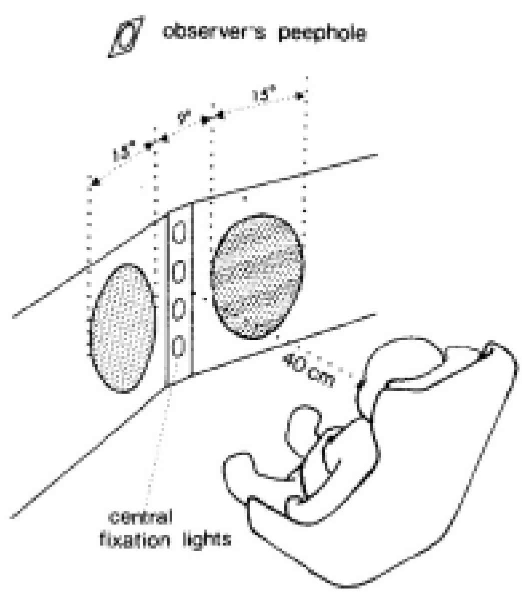

Figure 1. Figure from Atkinson *et al.* (1977), from original drawing by Oliver Braddick (reprinted with permission of the publisher).

The width of the bars of the grating (spatial frequency) is varied, to establish at which level of contrast the infant fails to show a preference as judged by the observer. A challenge is to keep the infant engaged on the task for a sufficient number of trials so that the data is statistically reliable. Fortunately, Braddick and Atkinson had a biddable infant on hand as their first subject: Fleur, their first child, born in 1973, who was 2 months old at the time of the experiment. This single case study was impressive at revealing a contrast sensitivity function that was similar in shape to that normally seen in adults, albeit with poorer sensitivity overall, including poorer acuity than adults. This study, the first measure of contrast sensitivity in an infant, was an important proof of concept in showing that the method of forced choice preferential looking had promise for studying small humans who could not describe what they saw.

Braddick and Atkinson had a sense of fun which could get them into trouble. They added Fleur's name to the list of authors on the *Nature* paper[4] that resulted from this study. Since Janette had retained her own surname, those who only knew of them from the published paper tended to assume that she was a research collaborator, and that Fleur Braddick was Oliver's wife. This led to sharp disapproval, initially, when Braddick and Atkinson booked a joint hotel room for a vision conference. Fortunately, Dick Cavonius enlighted the conference organiser (a strictly 'proper' senior academic professor) as to the correct Braddick family relationships and names.

Braddick and Atkinson went on to run further proof of concept studies using other behavioural developmental methods which they adapted for use with infants. In 1976 they published a paper[5] in which they estimated acuity in infants from the highest spatial frequency at 100 per cent contrast at which a preference could be demonstrated. Again, the challenges of doing this kind of study were substantial: they studied babies lying in a mobile crib, with visual stimuli projected above them. The method used was called 'sucking rate habituation /dishabituation'. The babies wore goggles so that they could view stereoscopic images, and the method measured their rate of sucking on a bottle teat as an index of interest (circumstantial evidence of ability to detect the disparities in the stereoscopic stimuli). Not all babies complied, and there were large individual differences across infants in sucking rates. What is more, the method did not work well for infants who were breast fed rather than bottle fed. Nevertheless, this study needed to be done. It established the value of the method in principle and revealed its limitations. Rather more successful was the visual habituation/ dishabituation method in which the infant is first shown one image of an object or striped pattern over and over again (habituation stage). As the infant becomes bored with the same image each time, looking declines. When the amount of looking reaches a predetermined criterion level, the

[4] Atkinson *et al.* (1974): 'Janette Atkinson, Oliver Braddick & Fleur Braddick'.
[5] Atkinson & Braddick (1976).

stimulus image is changed. Here the logic is that if there is a significant rebound of looking time when the new stimulus is presented after the habituation stage, then the infant must at least be able to discriminate the first stimulus from the second new stimulus.

Establishment of the Visual Development Unit

With an informality that would make today's University administrators blench, Braddick and Atkinson 'borrowed' a set of rooms in Trumpington Street from Horace Barlow. The accommodation was not at all suitable for an infant lab, so they set out to redecorate the premises with a jungle mural, turning up with tins of paint and ladders, to create a welcoming and child-friendly environment where the infants could play, feed and sleep, giving the parents a chance to relax. This enabled the infants to be in the best state for testing, usually just before or after a feed or when they had just woken up.

By 1975 they were ready to supplement their behavioural testing method with electrophysiology: averaging the tiny electrical responses from the scalp over repeated presentations of a visual stimulus: this allows one to detect a waveform with a distinctive timecourse, the visual evoked potential (sometimes now called 'visual event-related potential'), whose amplitude increases as the stimulus becomes more visible. They were ahead of their time in recognising the possibilities of what is now known as 'frequency tagging', a method where stimuli of different kinds are presented, with the image reversing at a given rate. The brain response can then be subjected to Fourier analysis, to extract components that are maximal at the same temporal frequency as the reversing stimulus. They were also ready with a new infant subject – Hugo, their second child, who was 6 months old at the time they developed this method. In a ground-breaking study[6] with Laurence Harris (then a student of Colin Blakemore), Braddick and Atkinson showed that visual acuity improved a great deal in the early months of life, and that the visual evoked potential gave data consistent with behavioural methods. This study also provides an early illustration of the flair shown by Braddick and Atkinson in devising methods that ensured babies would be attentive and interested in what could be rather dull tasks: they used a reflecting mirror to superimpose an image of an active face on the stimuli, realising that babies were far more interested in social stimuli than gratings.

A grant from the Medical Research Council allowed Braddick and Atkinson to develop this line of work further, and with research assistant Kathleen Moar they conducted a study comparing contrast sensitivity in three groups of infants, aged 5 weeks, 8

[6] Harris *et al.* (1976).

weeks and 12 weeks of age.[7] They demonstrated a steady improvement in contrast sensitivity over the first 3-4 months of life. The large improvement in contrast sensitivity between the youngest group and older babies raised a host of questions about the mechanism. Physiologists working with cats had ascribed improved acuity in young animals to the development of neuronal connections, and it seemed plausible that a similar process may occur in humans. This was of potential practical importance as well as theoretical significance, as it suggested that there may be an early 'critical period' during which it would be optimal to treat amblyopia ('lazy eye'), before neuronal connections had become established.

Nevertheless, it was not possible to be sure how far changes in acuity in the first few months of life were due to neurological rather than optical changes. To answer that question, Braddick and Atkinson adopted a new method similar to that developed by Howland and Howland in the early 1970s, called 'isotropic photorefraction'. A camera is placed so as to measure light reflected from the eye when a small safe flash of light is presented, making it possible to measure visual accommodation and to detect astigmatism and refractive errors (short or long sightedness) at any age. No co-operation is required from the infant, beyond looking at the camera, where an adult would wave an illuminated plastic duck on the end of a pen-torch, saying 'quack, quack', to keep the infant's attention for a few seconds. The method was both robust and rapid, taking about 5 minutes for the whole testing session with the infant.[8] Using this technique, Braddick and Atkinson measured astigmatism in 93 infants recruited from Cambridge Maternity Hospital.[9] They found that many infants under 12 months of age had significant astigmatism, but this decreased to adult levels by 2 years of age.[10] Accommodative error could not, however, account for the poor acuity seen in infants and young children.[11] At this point, it was becoming clear that the work they were doing had considerable clinical as well as theoretical significance, and they made contact with ophthalmologists and paediatricians to develop this aspect of their research. Braddick and Atkinson's third child, Lorrin, was born around this time, in 1977.

In 1979, with research assistant Jennifer French, Braddick and Atkinson studied 97 babies aged between 1 to 10 days using the visual evoked potential method to assess

[7] Atkinson *et al.* (1977).

[8] At a later stage Braddick and Atkinson, together with Howard Howland and John Wattam-Bell (a student at the time in the VDU), developed an instrument called the 'isotropic videorefractor', which gave images of the infant's refraction, instantaneously, on a video screen. This method avoided the cost of developing photographic images on film and meant that if any of the images were not clear the method could immediately be repeated to obtain a better image.

[9] Howland *et al.* (1978).

[10] Atkinson *et al.* (1980).

[11] Braddick *et al.* (1979).

contrast sensitivity.[12] Results suggested that acuity in these newborns was poor relative to that seen in older infants and adults, but nevertheless adequate to detect features of the mother's face at a close distance. Visual evoked potentials were also incorporated in a clever design that tested whether infants had binocular vision, using correlated and uncorrelated random dot stereograms, in a collaboration with Béla Julesz and other colleagues from the USA.[13] It was the first published study of development of stereopsis in very young infants and showed that most infants had binocular vision by 3-4 months of age.

Alongside the work on infants, Braddick retained an interest in fundamental visual perceptual processes in adult humans. He was fascinated by a central question – how we extract a percept of global motion from many individual motions. He put it so vividly in a later review paper[14] that it is worth quoting in full:

> We are often faced with visual stimuli that have an overall direction of motion but are made up of many diverse local motions. The turbulent but directed flow of water in a stream, gravel being dumped from a truck, or a flock of birds taking to the air, are examples. We also encounter stimui that show motion transparency, in which elements belonging to entities with different motions are interleaved or superimposed – for example a vehicle seen through the gaps in a hedge or fence, or the shadow that a moving object casts on a differently moving surface. (p. 995)

In 1980, he published a highly influential review of visual motion perception – this time, rather than the stereograms used to study binocular depth perception, his focus was on the random dot kinematogram.[15] This stimulus, first developed by Béla Julesz (1971), is a series of matrices, each with random black and white square elements. On successive presentations, some elements in the matrix are repeated, whereas others in the central region are displaced through a specific distance. When the interval between successive stimuli is very brief, this gives rise to a perception of movement of a coherent object, with a boundary between the central moving zone and the static surrounding area. This illusory movement must depend on some mechanism that computes the spatio-temporal relationship between elements. Braddick put forward a two-process theory of apparent motion, with a low-level short-range process that depends on directionally selective neurons in the visual pathway responding to discontinuous stimulation, and a higher-level process that interprets the input as a smoothly moving object. Braddick's logical analysis of the nature of motion perception set a research agenda for years to come.[16] This line of work involved psychophysical experiments of a more traditional kind, with observers

[12] Atkinson *et al.* (1979).
[13] Braddick *et al.* (1980).
[14] Braddick (1997).
[15] Braddick (1980).
[16] Braddick (1997); Prins (2008).

being tested in varying parameters over many trials to establish the conditions that influence perception; nevertheless, there is clear interplay between his work on adult perception and the developmental studies.

The Visual Development Unit in Cambridge went from strength to strength during the 1980s, which also saw the birth of Braddick's fourth child, Ione, in 1988. Orthoptist Shirley Anker joined the team, providing invaluable clinical expertise. By this time John Wattam-Bell, a neurophysiologist from Oxford, had also joined, embarking on a productive collaboration with Atkinson and Braddick that lasted for 30 years until his premature death in 2013. As noted above, as a student he had been involved in developing videorefraction methods to replace the more limited photorefraction that was previously in use. One of his earliest papers with Braddick and Atkinson[17] adopted a clever experimental paradigm that used a specific stimulus sequence designed to measure the visual evoked response of orientation-selective mechanisms in the brain. Intriguingly, this response was not apparent in newborns, but could be seen at 6 weeks of age. Bruce Hood, who subsequently became Professor of Psychology at the University of Bristol, joined the Visual Development Unit around this time as Atkinson's postgraduate student, with a particular interest in development of attentional mechanisms.[18]

Alongside these studies of typical infant development, Braddick and Atkinson had also developed a line of clinical research with babies and children who had visual problems with an ocular basis.[19] In 1992, however, they had the opportunity to study two infants (aged 4 and 8 months respectively) who had had surgery to remove the cerebral cortex on one side to relieve intractable seizures.[20] As might be expected, informal observations showed that these infants ignored toys placed in the half-field contralateral to the removed hemisphere, where removal of visual cortex should render them effectively blind, but readily reached for a toy placed in the ipsilateral half-field. Braddick and Atkinson used a fixation shift procedure, where the infant initially sees a central flashing target, which is replaced by a contrast-reversing target to either the left or right of centre. Both infants responded at above chance levels to targets in the contralateral field; i.e., orienting behaviour was evoked by stimuli that cannot have been processed by contralateral cortex. This observation was reminiscent of the phenomenon of 'blindsight' previously described in adults who still oriented to stimuli in a 'blind' visual field, despite expressing no awareness of the stimulus, and it provided evidence that orienting depended on a subcortical route. A further condition was run with one of the children, in which the central flashing stimulus remained on when the lateralised target was presented. This creates a situation where stimuli compete for attention, and performance on

[17] Braddick *et al.* (1986).
[18] Atkinson *et al.* (1992).
[19] Ehrlich *et al.* (1995).
[20] Braddick *et al.* (1992).

the contralateral side was much lower in this case. This observation led to development of the Fixation Shift Paradigm as a diagnostic tool. The ability to shift attention when there is no competition is evidence that the infant has developed the subcortical route for orienting, which is typically seen as early as one month of age. The ability to disengage attention from a competing stimulus involves cortical systems, and emerges in typically developing infants around 3-5 months of age. Thus, inclusion of competition and non-competition conditions can be a particularly sensitive diagnostic indicator of neuro-developmental problems. This line of work also made it clear that one cannot study visual perception without studying attentional selection: the brain's perception of an object does not depend just on its physical properties, but also on what other objects are present in the visual field.

University College London

In 1993, Braddick moved to University College London (UCL), together with Atkinson, as professors of Psychology. They maintained the Visual Development Unit in Cambridge, where they were running major screening studies of young infants, but also created a new Visual Development Unit in London. In 1998, Braddick became Head of the Department of Experimental Psychology at UCL.

Braddick's basic psychophysical studies on processes of visual motion perception continued during this period. The use of displays with moving dots allowed one to establish a 'coherent motion threshold'. Figure 2 illustrates the type of stimulus that is used. Most of the dots in the display move at random, but a proportion move coherently in one direction, giving a perception of motion. By varying the proportion of coherently moving dots, one can establish the lower limit for movement detection – typically around 5 per cent in adult humans.[21] This task can also be performed by non-human primates, and it appears to depend on neurons in cortical area V5 (also known as MT). The conclusion is that area V5 is involved in combining information from lower-level motion signals to create a synthesised global motion percept. One point about this task is that the threshold depends on the similarity between the random dots and the coherent dots: if they are different colours, then motion can be detected at much lower levels of coherence. Another point that assumed importance in later work was that one can use a similar task with non-moving stimuli to study coherent form detection, i.e. the detection of a form in a random field, defined by stimulus similarity (e.g. from bars that share the same orientation). This depends on a ventral visual stream, as opposed to the dorsal stream that mediates motion perception.

[21] Braddick (1995).

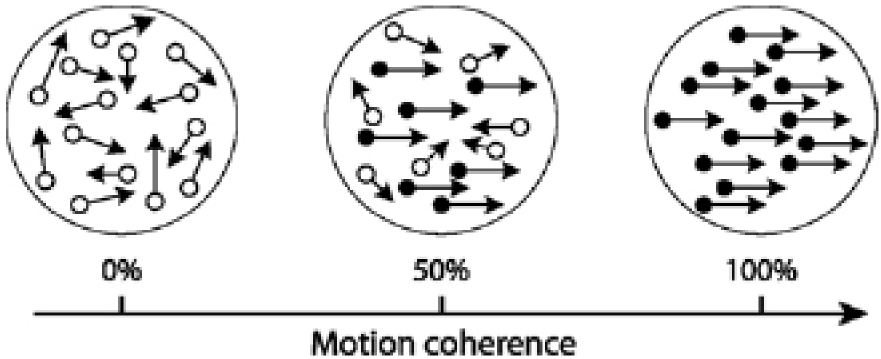

Figure 2. Schematic diagram of stimuli from random dot motion task. In each frame a proportion of the dots (shown in black) are repositioned with fixed spatial offset, and the remaining dots are repositioned randomly. Figure from Zhang (2012), reproduced under CC BY 4.0 licence.

In 1996, Braddick and Atkinson published two major studies that demonstrated the clinical utility of their approaches to assessment.[22] They had by this time developed videorefraction as a method to accompany photorefraction, making it possible to identify infants with lags in visual accommodation. For their first study, on screening, every infant living in the City of Cambridge over a 2-year period was invited to come for screening using photorefraction. Of the over 3000 infants who were assessed, around 5-6 per cent had evidence of visual problems and were referred for follow-up. In the second study, over 5000 infants were tested with videorefraction around 8 months of age; in this study infants with significant hyperopia (far-sightedness) were randomly assigned to receive spectacles or not, and then followed up at 4 years of age. The first study showed that screening was effective in identifying infants who were at risk of developing strabismus (squint) at 4 years of age, and the second study indicated that this risk could be reduced by providing infants with corrective spectacles. Videorefraction was safer and easier than retinoscopy for testing infants and children, because the testing was faster and did not require the user to be trained in retinoscopy. In addition photo/videorefraction assessed the two eyes simultaneously, so their refractive state could be compared, whereas in retinoscopy, the refractive measures were made sequentially. These studies on early identification and intervention were important, given the evidence that an opportunity to form optimal neuronal connections may be missed if diagnosis is delayed. The videorefractive screening programme was subsequently rolled out in Spain, Portugal, France, Germany and Italy, as well as in the UK.

[22] Atkinson *et al.* (1996).

Subsequently, the children initially studied in the Cambridge screening project provided an invaluable opportunity to look at long-term outcomes of infants with visual problems. A follow-up study of outcomes up to 7 years of age not only confirmed that the screening was effective at picking up visual problems, and early prescription of spectacles could help ameliorate these, but also that children with such problems were more likely to have broader learning difficulties.[23] This study illustrated the value of multidisciplinary working: most studies of infant vision restricted themselves to looking at the function of the eye; by extending the assessment more broadly, Braddick and Atkinson were able to uncover neurodevelopmental interconnections between visual and cognitive functions.

London provided an opportunity for enhanced collaborations with paediatric neurology colleagues, and Braddick and Atkinson developed a new line of research on visual functioning in children with perinatal brain damage,[24] an interesting topic both in terms of identifying clinical needs in these children, and in terms of understanding more about the brain's ability to show plasticity and neural reorganisation in the face of disruption to connections. They also now had opportunity to work with children whose brains had been scanned using MRI, making it possible to relate their visual findings to underlying neuropathology.[25] There developed a rich seam of research with paediatric neurologist Eugenio Mercuri at the Hammersmith Hospital, which also led to a long-term collaboration with Giovanni Cioni, child neuropsychiatrist from the Stella Maris Scientific Institute at the University of Pisa.

Around this time, they also started a research programme on perception in children with Williams syndrome, a rare genetic condition that leads to a distinctive phenotype that includes visuo-spatial weaknesses that seem disproportionate, in relation to their more general intellectual disability and their relatively good speech and language development. Using measures that contrasted different motion and form processing they postulated that children with Williams syndrome had a specific deficit with development of the dorsal visual stream, which encodes spatial relationships and the visual control of action.[26] This was a completely new way of thinking about the Williams syndrome phenotype, which generated clear predictions for future studies. Intriguingly, a similar pattern of selective impairment of coherent motion detection, relative to coherent form detection, was also found in children with autism[27] and a range of other neurodevelopmental disorders.

[23] Atkinson *et al.* (2007).
[24] Mercuri *et al.* (1996).
[25] Mercuri *et al.* (1999; 1997); Ricci *et al.* (2006).
[26] Atkinson *et al.* (1997).
[27] Spencer *et al.* (2000).

One prediction was that measures of form coherence and motion coherence should activate the traditional ventral and dorsal visual processing streams. In 2000, Braddick and Atkinson published a paper showing that, while the tasks activated different brain networks, they did not neatly correspond to the traditional dual stream pathways.[28] The term 'dorsal stream vulnerability' had become an established way of referring to the selective deficits in visual motion processing that were being discovered in a range of clinical conditions, and Braddick and Atkinson continued to use it,[29] but it was clear that the neurobiological basis might be more complex than suggested by this designation.

Braddick and Atkinson were regular visitors to the University of California at San Diego where they taught an annual summer school course. This gave them the opportunity to enjoy seaside life with their young family over the summer, and also to establish strong links with Ursula Bellugi, from the Salk Institute for Biological Sciences in San Diego, who had a longstanding interest in Williams syndrome. She tried to persuade Braddick and Atkinson to travel the country to do visual testing on a US sample of adults with Williams syndrome, but they suggested a more feasible option would be for them to train Bellugi's research staff in the methods, which is what ensued. This study confirmed persistence of visual motion processing deficits into adulthood in this population.[30]

University of Oxford

In 2001, Braddick took up the Chair of Experimental Psychology at the University of Oxford, a post that entailed acting as Head of Department. This led to the third incarnation of the Visual Development Unit, an area on the ground floor of the Tinbergen Building that was beautifully decorated with a jungle frieze painted by Braddick and Atkinson's adult children. Atkinson officially remained at UCL, continuing to direct the Visual Development Unit there, but also taught courses in medicine and neuroscience, and supervised research and students in Oxford.

In Oxford, Braddick found many eminent colleagues whom he had first known in Cambridge: Colin Blakemore was Professor of Physiology, and Braddick's previous graduate student, Andrew Parker, was based in the same department. In psychology, the former Professor and Head of Department, Larry Weiskrantz had a shared interest in blindsight, as did Alan Cowey, who had done seminal work on visual systems in monkeys. However, the reunion with these old colleagues was marred by the fact that they were

[28] Braddick *et al.* (2000).
[29] Braddick *et al.* (2003).
[30] Atkinson *et al.* (2006).

targeted by animal rights activists. Colin Blakemore had adopted the approach of open dialogue with those opposing animal research, but had at times needed police protection. Alan Cowey was also a particular target for his work on monkeys, and the presence of animal labs at the top floor of the building meant that there were regular protests at the entrance of the building. Initially, the protesters used loud-hailers, which was seriously disruptive to Braddick's research with babies, but eventually an injunction was served which limited the amount and nature of protest that was allowed. Nevertheless, there were at least three incidents of arson affecting members of the psychology department during Braddick's time as Head of Department, though none of them involved anyone who worked with animals. In time, the more dangerous protesters responsible for such incidents were arrested, and life became quieter. Nevertheless, this topic remained a significant source of stress for those working in the department, and in particular for Braddick as Head of Department. He had a strong sense of humanity and fairness, and although he was well aware of the major insights that had been achieved through research on animals, he also was at pains to ensure that any research done in his department was justified and properly regulated.

Braddick had long been interested in visuo-motor interactions, and in Oxford he was able to develop this line of work further, creating a large space for assessment of motor skills. Graduate student Dorothy Cowie experimented with a new method, kinematic markers (luminous patches stuck onto limbs) to study visual guidance of stepping movements,[31] and Marco Nardini led a study on use of landmarks by children and adults to control navigation.[32]

In his year of retirement, 2011, Braddick, with Atkinson, published a masterly review of development of human vision function, drawing on work of the previous 25 years.[33] This illustrates the huge developments in theory and methods that had occurred since they had conducted their first studies on infants, and the numerous clinical applications to both vision and paediatric neurology.

After official retirement and up until his death Braddick continued to work with Atkinson to develop an Italian translation, as well as an iPad version, of their attention battery for young children (ECAB-Early Child Attention Battery).[34] The ECAB was found to be sensitive to perinatal brain injury in a follow-up study of 4-year-olds, conducted in collaboration with Oxford neonatologists.[35] The attentional deficits identified with the ECAB were distinct from generally lower cognitive performance on a standard intelligence test. The same study acted as a pilot trial of the effect of a unique dietary

[31] Cowie *et al.* (2008).
[32] Nardini *et al.* (2008).
[33] Braddick & Atkinson (2011).
[34] Breckenridge *et al.* (2013); Coratti *et al.* (2020).
[35] Atkinson *et al.* (2022).

supplement designed to promote brain development; results were promising enough to justify a much larger trial (DOLFIN), that is being rolled out in 2022.

Another major strand of work focused on clarifying and extending the earlier observations of global visual motion sensitivity in development. The different developmental trends for detection of global motion vs global form had been reliably replicated, with motion sensitivity showing a more protracted course, and frequently being impaired in a wide range of neurodevelopmental disorders.[36] In a study with collaborators in San Diego, Braddick and Atkinson considered brain and behavioural correlates of global visual motion sensitivity in 154 typically-developing children aged from 5 to 12 years.[37] This showed that individual differences in motion sensitivity were not associated with growth of extrastriate visual areas (MT) of the dorsal stream, i.e., those which are involved in initial processing of motion, but were linked to development of specific areas of the parietal lobes, to which the dorsal stream projects, and to structural asymmetry of the superior longitudinal fasciculus.[38] Furthermore, performance on global motion sensitivity showed a specific association with visuospatial and numerical abilities.

Braddick and Atkinson were always interested in the clinical implications of their work, rather than treating research participants just as experimental subjects. This led them to take on the writing of international guidelines for individuals with Williams syndrome from infancy to old age in terms of their visual and cognitive functioning: part of a collaborative effort with 50 medical and scientific experts from around the world. Sadly, Braddick died before this was completed, but Atkinson is continuing this important work.

Braddick as a scientist

Braddick was generally affable, with a leadership style that operated through consensus rather than command. I can remember only one occasion when he was really irritated – unfortunately, an occasion that I unwittingly instigated! In 2017, after Braddick had retired, the Oxford Experimental Psychology Department suffered a disaster when asbestos was discovered in heating ducts. The building had to be evacuated within days, with staff dispersed to temporary locations throughout the city. A year later, most of us moved into a prefabricated building, which would be our home for a few years while the original building was decontaminated, demolished and rebuilt (a process still continuing in 2022, as I write this). The prefab – the Anna Watts Building – was functional but grey

[36] Micheletti *et al.* (2021).
[37] Braddick *et al.* (2016).
[38] Braddick *et al.* (2017).

and anonymous, and I had the idea that we should identify our meeting rooms – currently known only by names such as 2.04 or 1.26 – with pictures of visually interesting psychological phenomena, such as visual illusions, simultaneously making them more memorable and decorative, while providing a psychologically relevant theme. I had assumed Braddick would be enthusiastic about this idea, and so was dismayed to find that he was the only person who responded with strong opposition. It turned out that he had just written an editorial for *Perception*,[39] in which he laid into the study of visual illusions with uncharacteristic venom. The editorial is a masterpiece: in a few short paragraphs, he makes it clear that his beef is with the way people use the 'Wow!' factor of illusions to try to persuade undergraduates that perception is interesting, even though many illusions are still not understood and do not form a coherent topic for investigation. It is perhaps a testament to Braddick's equable personality that he remained friendly with me even though my idea was implemented, and there is now a Müller-Lyer room and an Ebbinghaus room in the Anna Watts building.

In contrast to many vision scientists, Braddick had remarkably wide-ranging interests. He was a believer in interdisciplinary research, and his own research corpus is a testament to the success of that approach, combining insights from physics, psychology, neuroscience, orthoptics, ophthalmology and paediatrics. He and Atkinson were also conspicuous for attending talks well outside their area, and asking thoughtful questions in a way that was stimulating without being hostile. In a wonderfully warm obituary,[40] his fellow vision scientists Peter Thompson, David Burr and Michael Morgan capture it perfectly: 'At so many conferences, be it Vision Sciences Society (VSS), European Conference on Visual Perception (ECVP), Association for Research in Vision and Ophthalmology (ARVO) or specialized workshops, he could be counted on to ask the right question – the question that needed to be answered, rather than the question to show how clever he was.' He would express regret that in recent years, graduate students seldom attended talks outside their specific field of interest, believing that some of his best ideas had come from the novel perspective offered by questions and methods from a different area of psychology. In an in interview about his career, published in *Current Biology* in 2017,[41] Braddick gave the advice: '... remain open-minded to a wider input – make time to find out through seminars and reading what's going on in areas that aren't quite yours. Sometimes going to a seminar that isn't quite your area of research helps you expand your ideas and even move in a new direction.'

[39] Braddick (2018).
[40] Thompson *et al.* (2022).
[41] Anonymous (2017).

Braddick had no ambition to set up a huge research empire. He enjoyed a hands-on approach to experiments, working directly with graduate students and postdocs, rather than being a remote head of the laboratory. He also was an enthusiastic teacher, and many studies had their origins in undergraduate projects, which he and Atkinson continued to supervise despite their seniority.

This attitude to science, pursuing it for its intrinsic interest rather than for any associated glory, and encouraging the next generation of vision scientists, made him a popular colleague. He is fondly remembered not just as an inspirational scientist but also as a fair-minded and hard-working Head of Department in both UCL and Oxford. He was also a good academic citizen, supporting vision research with stints on the editorial boards of Perception, Vision Research and Current Biology, and serving as a trustee for the Association for Research in Vision and Ophthalmology.

Braddick was not one to thrust himself forward, but there was no need for him to do so – his qualities and achievements were evident to all who knew him. He was elected as a Fellow of the Academy of Medical Sciences in 2002, and a Fellow of the British Academy in 2012.

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