



Research Review™

EDUCATIONAL SERIES

Multi-sensory stimulation and infant development

About the Reviewers



Dr Simon Rowley
MB ChB (Otago); FRACP

Consultant Paediatrician and Neonatologist, Auckland City Hospital

Dr Simon Rowley, a senior neonatologist in the Auckland region has had key roles in undergraduate and postgraduate medical education throughout his career, and has been an Honorary Senior Lecturer in the Department of Paediatrics: Child and Youth Health since 1986. Dr Rowley's roles include leading neonatal tutorials for undergraduate medical students, demonstrating newborn examination on video for myPaediatrics, chairing the Paediatric Vocational Training Committee (a role he has held for the last 6 years), organising Neonatal Grand Rounds (for 12 years), and instructing in Neonatal Intensive Care Unit Stimulation Workshops.

Dr Rowley has also had a prominent profile in the community with Plunket nurse teaching, and is a founder member of The Brainwave Trust Aotearoa NZ which promotes education and awareness of the importance of early experience in shaping the neurobiology of the developing brain.

Simon is married, his wife lectures in early childhood education and they have 4 adult children.



Dr Jane Williams
RN (Paeds), BMgt, CertTertTeach, PhD

Dr Jane Williams is one of Australia's leading experts on child development. She is the Director & Research and Education General Manager for GympaROO & KindyROO, a Neuro-Developmental Consultant, and Adjunct Senior Lecturer at James Cook University School of Nursing, Midwifery and Nutrition where she teaches students about the important first years of life. Her past research has focussed on the important role that parents play in the detection of early, but subtle, developmental problems that may give rise to later learning problems at school. More recently Jane has investigated the effects of effects of a sensorimotor program on school aged children's performance both in the classroom and in the playground.

As Editor of *First Steps* a magazine dedicated to parent education, she focused on helping parents understand their child's development. Dr Williams also has a number of journal publications aimed at drawing the attention of early childhood health professionals to the importance of early childhood development, prevention and early intervention.

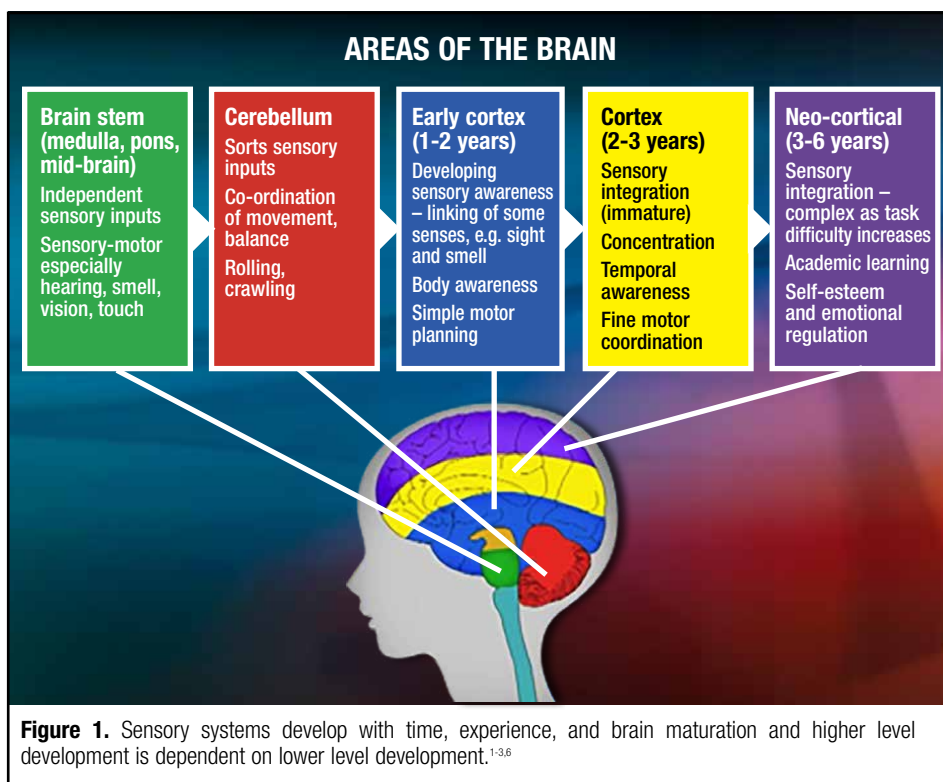
The focus of this review is the science of sensory development and stimulation in neonates and infants and, in particular, the importance of multisensory stimulation. The primary senses discussed are touch, hearing, vision, balance, and smell. This review is intended as an educational resource for primary healthcare professionals involved in neonatal and infant care and development, including GPs, paediatric nurses and midwives, as well as pharmacists and pharmacy assistants.

Introduction

Sensory development is a complex process involving both morphological and neurological components.^{1,2} The basic physical structure of the sensory receptors develops early in pregnancy; however, most development of the senses occurs during the last 16-20 weeks of gestation, in response to *in utero* stimuli. The sensory systems then mature rapidly in the first year of life and continue to mature with time, experience, and brain maturation (**Figure 1**).^{1,2} External experiences and stimulation of sensory systems via physical, chemical, sensory, and social/emotional environments play a key role in shaping the development of the infant brain.²

Experiences in early life are related to how successfully a child will perform socially, emotionally, and academically later in life,³ and the brain is more responsive to stimulation during the first three years of post-natal life than at any other stage of life.^{4,5} Moreover, early life experiences influence gene expression, which in turn determines brain architecture.⁶ Early life experiences also shape the development of lower level neural circuits upon which higher level circuits responsible for more sophisticated mental functions are dependent for the input of precise and high quality information (**Figure 1**).^{3,6}

The major influence of early life experiences and external stimuli on brain and sensory system maturation emphasises the important role of sensory stimulation in optimising infant growth and development.



Tactile sense (touch)

There is a connection between touch, the skin, and brain development, with the developing cerebral cortex being influenced by tactile (somatic) stimulation.⁷ Touch affects developing physiological, biochemical, and psychological functions.⁹ The importance of tactile stimulation is emphasised by the WHO recommendation to provide skin-to-skin contact starting at birth to facilitate child development.⁹

Early mother-infant skin-to-skin contact has been demonstrated to reduce crying and benefit breastfeeding outcomes and cardio-respiratory stability in healthy new-born term infants, according to a meta-analysis of randomised trials that compared early skin-to-skin contact with standard care.¹⁰ In preterm infants, randomised controlled studies have shown that skin-to-skin contact via moderate-pressure massage can reduce stress behaviours in preterm infants¹¹ and facilitate weight gain.¹²⁻¹⁴ Increased vagal activity, gastric motility, and insulin levels following moderate pressure massage are possible mechanisms underlying the observed weight gain in preterm infants.¹⁵ Tactile stimulation is important throughout infancy as evidenced by developmental deficits in children raised in environments in which they were deprived of touch.¹⁶

Auditory sense (hearing)

Hearing is the most developed sense at birth and the first exposed to stimulation that drives development of the neural pathways.¹ Functional hearing develops at 25-27 weeks' gestation, with low-frequency sounds, such as the mother's heartbeat and speech, eliciting physiological responses *in utero*. The maturing foetus responds to a wider range of sound frequencies through to the third trimester.¹ In infants, sounds generate memory in the auditory and language regions of the cerebral cortex and stimulate the development of neurological connections to the limbic system.²

In clinical investigations of the effects of auditory stimulation on autonomic and neurobehavioral development in early life, randomised and longitudinal case-control studies have shown that maternal sounds, such as singing or speaking in a soft soothing voice, result in reduced heart rate in pre-term infants.¹⁷⁻¹⁹ Maternal sounds were also associated with improved feeding behaviours and enhanced mother-infant bonding, thereby reducing parental stress associated with pre-term infant care.¹⁷

ABOUT RESEARCH REVIEW

Research Review is an independent medical publishing organisation producing electronic publications in a wide variety of specialist areas. Research Review publications are intended for New Zealand medical professionals.

SUBSCRIBE AT NO COST TO ANY RESEARCH REVIEW

NZ health professionals can subscribe to or download previous editions of Research Review publications at www.researchreview.co.nz

Visual sense (sight)

Vision is poorly developed at birth but matures rapidly with stimulation in the first few months of life.^{20,21} Maturation of the visual system, including neurological and ocular components, is influenced by many factors including prenatal and postnatal nutrition and postnatal visual stimulation.²⁰ The visual cortex is the part of the brain responsible for processing visual information.²¹

There is experimental evidence that, from birth, infants prefer direct eye contact as a form of communication and that enhanced neural processing occurs during infant-parent direct eye contact.²² Indeed, the WHO recommends that parents should engage in direct eye contact with their infant starting at birth.⁹ This early sensitivity to mutual gaze is likely to support the development of social skills later in life.²² Visual stimulation also appears to enhance auditory processing in infants.²³

Olfactory sense (smell)

The development of smell in infants has not been as well researched as that of other senses; however, some general observations include babies preferring sweet odours such as lavender and vanilla and exhibiting an acute avoidance response to foul odours.¹

There is accumulating evidence of a particularly strong connection between olfactory stimulation and emotional processing. Studies indicate that, in humans, memories recalled by odours are more emotionally potent than those recalled by the same cue presented visually or as sound,²⁴ with the specific emotions able to be elicited through the olfactory pathway being happiness, disgust, and anxiety.²⁵ It has also been shown that, in neonates, learning is enhanced when olfactory stimulation is combined with tactile stimulation.²⁶

Against this background, it is perhaps not surprising that an infant's ability to smell is an important part of the early infant-mother bonding process.^{1,27} Indeed, components of the maternal diet reach the amniotic fluid, are swallowed, and become familiar to the foetus and thus may contribute to the scent of the mother, including her breast milk.¹ Infant-maternal attachment relies on infants acquiring learned preferences to the maternal odour.²⁷ As early as 2-days-old, complex associative olfactory learning is observed in newborns²⁸ and infants who experience skin-to-skin contact with their mothers are able to recognize their own mother's axillary odour.²⁸ Moreover, presentation of the maternal odour to a distressed infant has been shown to reduce crying and increase mouthing, which may facilitate feeding in newborns.²⁹ In another study, infants' social attention to faces was enhanced in the presence of maternal odour.³⁰ When looking at a face, the infants looked longer at the eyes than at any other facial region but they looked at the eyes significantly longer in the presence of maternal odour.³⁰ Also, just as there is evidence that infants can identify their mother's odour, there is also evidence that mothers are able to identify their infant's odour.³¹ Collectively, these observations emphasise the role of odour in facilitating the infant-mother bonding process.

It is not only maternal odour that can influence responses in infants. According to three controlled studies, other odours, including pine, baby powder, lavender and vanilla, can ameliorate emotional distress and support mood regulation in infants.³²⁻³⁴ Familiarity of odour (whether maternal or other) may be a factor in the calming effects of odours in infants.^{34,35} For example, presentation of a familiar odour (e.g. vanilla) to infants during a minor painful procedure (heel prick or venepuncture) was associated with less crying relative to infants presented with an unfamiliar or no odour during venepuncture.³⁵

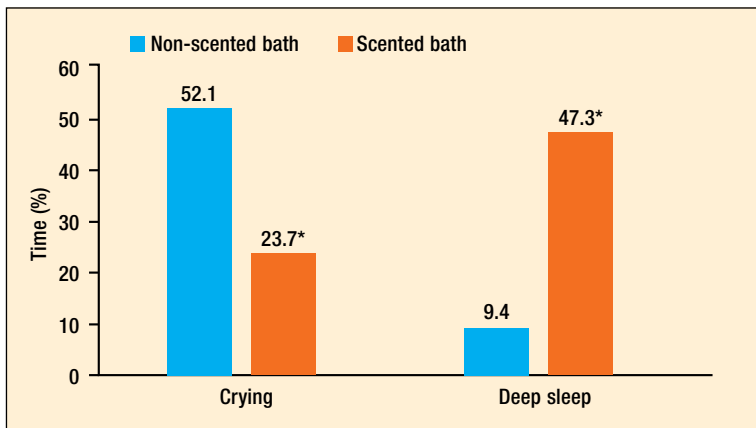


Figure 2. Post-bath behaviour (percentage time crying and in deep sleep) in infants bathed with lavender-scented bath oil (n=10) versus infants bathed with unscented bath oil (n=10) in a randomised study.³³ *p<0.05 versus unscented bath

In one of the controlled studies of the effects of non-maternal odours in infants, infants (aged 1 week to 4.5 months) were randomly assigned to be bathed by their mothers either with or without lavender-scented bath oil.³³ Infants in the lavender bath oil group spent a significantly (p<0.05) greater percentage of the bath time looking at their mothers than infants in the unscented bath oil group, and they also cried less and spent more time in deep sleep after the bath (**Figure 2**). Moreover, the mothers in the lavender bath oil group were more relaxed and smiled and touched their infants more during the bath than their counterparts in the unscented bath oil group.³³ The behavioural data indicating increased relaxation of the infants and their mothers were supported by their salivary cortisol levels being significantly reduced during the scented bath time (**Figure 3**).³³

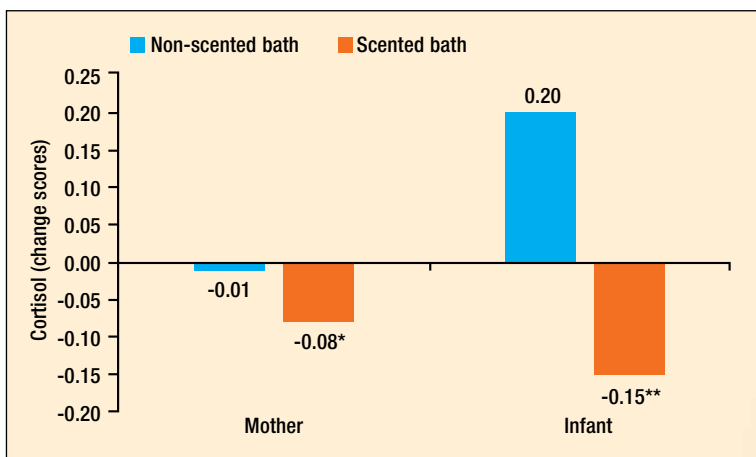


Figure 3. Salivary cortisol levels in infants (n=10) and their mothers (n=10) after bathing the infants using a lavender-scented bath oil in a randomised study.³³ *p<0.05 versus unscented bath; **p<0.005 versus unscented bath

There is also evidence that odour may contribute to infant learning. The presence of odour (pine or baby powder) has been demonstrated to increase attention (looking time) to an audio-visual presentation of a woman expressing happiness and sadness,³² and the presence of maternal odour to increase an infant's attention (looking time) to faces and eyes.³⁰ These findings are supported by the observation that odour enhances attention towards visual objects in adults.³⁶ It is suggested that these results have implications for optimizing infant environments for and cognitive development.³²

Vestibular sense (balance and movement)

The vestibular structures are morphologically well developed at birth but continue to develop during the first post-natal month.³⁷ The vestibular system has a close relationship with the cerebellum, which is critical for motor control co-ordination and the timing of movement. Important functions of the vestibular system are perception of movement, oculomotor and postural control, and spatial memory, all of which are influenced by gravity.³⁷ Indeed, there is accumulating evidence that vestibular dysfunction may delay the achievement of head control and independent walking in infants.³⁸ The vestibular system may also be involved in regulating the autonomic system, including arterial pressure regulation and bone mineralisation.³⁷

Arousal levels, visual alertness, visual tracking behaviour, and motor and reflex development in infants have all been shown to be influenced by vestibular stimulation in the form of rocking, spinning, or other movement experiences.³⁹ As an example of facilitating motor development during infancy, daily postural and movement activity training rapidly advanced head control (a major motor milestone) as early as 4-6 weeks of age in a randomised controlled study, with caregiver handling and caregiver-infant interactions being contributing factors.⁴⁰

Multisensory stimulation

A large evidence base exists that supports the association of multisensory stimulation, i.e. concurrent stimulation of auditory, tactile, visual, vestibular, and/or olfactory senses, with a broad range of benefits, including improved social, emotional, cognitive, and physical development in infants.⁴¹⁻⁴⁹ For example, multisensory stimulation in preterm infants has been demonstrated to improve language and motor skills at age 2 to 3 years.⁴⁹ Another example of multisensory stimulation is the demonstration that gaze and infant-directed speech experienced together stimulate the development of early social skills.⁴¹ Vision and hearing are the most important senses for effective learning.¹ Examples of structured multisensory stimulation modalities, which include both visual and auditory stimulation components, are the ATVV intervention and bedtime routine.

SUBSCRIBE FREE TO

MIDWIFERY RESEARCH REVIEW

Midwifery Research Review is a regular publication with papers selected by and commented on by Jackie Gunn, Senior Lecturer in the Dept. of Midwifery at AUT University. Live links allow readers to delve deeper into the topic. It is free to receive and the electronic format means you can print, save, and share with ease.

Time spent reading Midwifery Research Review has been approved by the Midwifery Council of New Zealand for NZ midwives as elective education.

ATVV intervention

The auditory-tactile-visual-vestibular (ATVV) intervention typically involves infant-directed talk via a soothing female voice (auditory stimulation) during a 10 minute massage (tactile stimulation) followed by 5 minutes of horizontal rocking (vestibular stimulation).^{46,47} It has been studied mainly as a preterm infant multisensory intervention.

In two randomised controlled studies, the ATVV intervention has been demonstrated to promote nipple feeding,^{43,46} and to increase alertness and reduce the duration of hospitalisation⁴⁶ in preterm infants. Improved maturation of oral feeding in preterm infants indicated by a faster transition to complete nipple feeding was an important finding of both studies.^{43,46} ATVV as a short-term intervention in the first year of life of preterm infants has also been shown to have important benefits for mothers and their infants in a randomised controlled study that examined the effects of maternally-administered ATVV intervention on maternal distress and the mother-infant relationship.⁴²

The underlying benefit of multisensory stimulation may be in the reduction of infant stress.⁴⁷ The ATVV multisensory stimulation intervention has also been demonstrated in a randomised controlled trial to reduce stress levels as measured by salivary cortisol levels in healthy term infants.⁴⁷ This is a desirable effect given the potential for stress to negatively affect brain development.⁷ Also, in practical terms, the results provide indirect support for the important role that multisensory maternal/caregiver comforting can play in reducing infant stress in commonly encountered clinical situations such as blood draws and vaccinations.⁴⁷

The mechanism of stress reduction involves the hypothalamic hormone, oxytocin, which is associated with increased social interaction and well-being as well as anti-stress effects.⁵⁰ Oxytocin is released in response to tactile stimulation such as touch, stroking, and massage. It is also released during contact between mothers and infants involving seeing, hearing, and smelling, and in response to suckling and food intake. The presence of increased levels of oxytocin in the brain, in response to sensory stimulation associated with these types of interactive behaviours, contributes to everyday infant wellbeing and mother-infant bonding.⁵⁰

Another potential benefit of the ATVV intervention is a positive effect on neuromotor development. In a randomised controlled study, multisensory stimulation via the ATVV intervention facilitated tonal maturation in preterm infants.⁴⁸

Bedtime routine

Another example of structured multisensory stimulation is that of the daily bedtime routine, and its potential benefit in the facilitation of night time sleep in infants, maternal mood, and the mother-infant relationship.

Australian and New Zealand epidemiological studies suggest that problematic sleep behaviours are common in young children, with approximately 30% of parents reporting that their infant or toddler had a sleep problem.^{51,52} This estimate appears consistent with North American research suggesting that 20-30% of infants and toddlers experience problems sleeping.^{53,54} There is also considerable evidence from North America that behavioural interventions for the treatment of sleep problems in children are efficacious, including a bedtime routine as a part of a multi-component treatment programme.^{53,55} Against this background, establishing a consistent bedtime routine is often recommended to parents to improve sleep quality in their children.

The efficacy of a bedtime routine (as an independent intervention) on infant and toddler sleep, and on maternal mood, was assessed in a randomised study performed in the US.⁴⁵ Using a two-age group design, mothers and their infant (ages 7-18 months) or toddler (ages 18-36 months) were randomly assigned to follow their usual bedtime routine or to follow a specific bedtime routine for a period of two weeks after a 1-week baseline period. The bedtime routine involved three sequential steps:

1. Bath using a provided wash product.
2. Massage using a provided massage product.
3. Quiet activities such as cuddling, singing, lullaby.⁴⁵

Such a routine can be considered multisensory since it combines the demonstrated benefits of stimulation of an infant's tactile (skin-to-skin contact with mother³³), visual (direct eye contact with mother^{22,33}), auditory (mother's voice⁵⁶), and olfactory (familiar scents – that of the mother²⁹ and/or the bath products used³³) senses.

In the infant cohort, the pre-bedtime routine resulted in significant ($p < 0.001$) reductions in the number and duration of night wakings (**Figure 4**) and in time to sleep onset compared with baseline.⁴⁵ Sleep continuity also increased and there was a significant reduction in the number of mothers who rated their child's sleep as problematic. Similar improvements in sleep quality and quantity were observed in the toddler group. Maternal mood was also significantly improved in the infant cohort. In contrast, sleep patterns and maternal mood in the control group did not significantly change versus baseline over the 3-week study period.⁴⁵

These findings are supported by those of a large multinational (10,085 mothers from 14 countries) study, which included centres in Australia and New Zealand.⁴⁴ It demonstrated a regular nightly bedtime routine to be associated with improved sleep in young children (aged 0-5 years), and that the benefit was dose-dependent – the earlier and more consistently the routine was instituted the better the response.⁴⁴

Sensory overstimulation

While sensory stimulation is clearly important for infant neurodevelopmental outcomes, excessive or inappropriately timed stimulation can have deleterious effects on premature infants whose brains are immaturely developed and unskilled in the filtering of sensory inputs. In particular, the environment, schedules, and procedures of the traditional neonatal intensive care unit (NICU) present the potential for sensory overload and absence of neuro-biological rhythms that are incompatible with the developing nervous system's expectations during a sensitive time of brain development.^{57,58} Individual infant assessment and application of sensory stimulation interventions in NICUs as well as adoption of procedures that avoid stimulatory overload or inappropriate patterns of stimulation have been advocated.^{57,59}

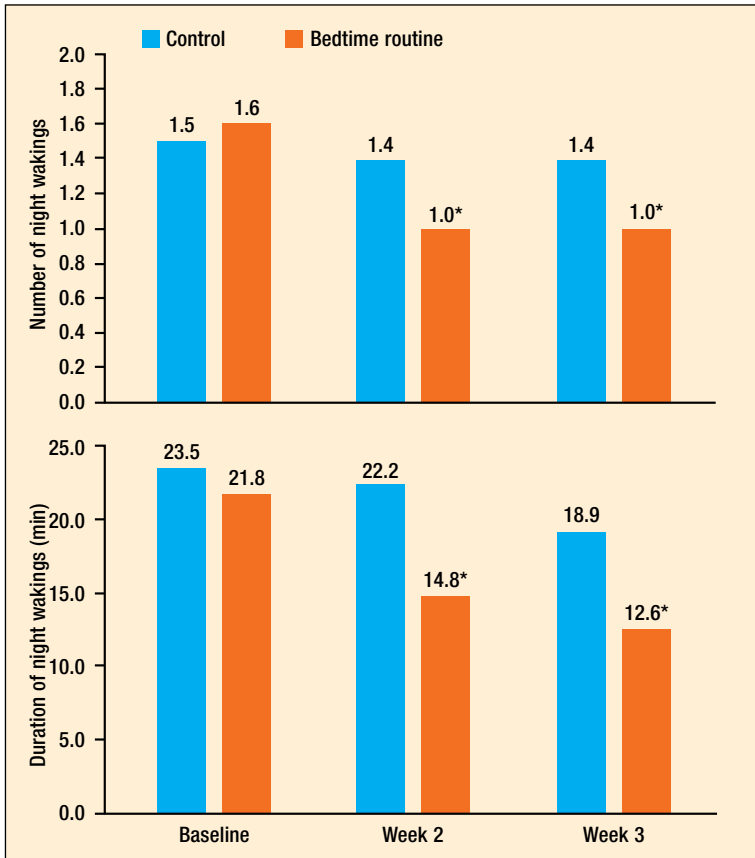


Figure 4. Number and duration of night wakings in infants (n=206) following a consistent bedtime routine.⁴⁵ *p<0.001 versus baseline

Expert commentary: Jane Williams

The importance of multisensory stimulation in infancy has long been discussed. Jean Piaget, the famous developmental psychologist, observed in his Theory of Cognitive Development (1936) that infants progressively construct knowledge and understanding about themselves and the world by coordinating multisensory experiences with physical interactions.⁶⁰ While his theory was based purely on observation, modern research techniques such as fMRI studies, alongside longitudinal studies of infants and children who have been deprived, or at risk of deprivation or overstimulation (pre-term infants in NICU for example), more specifically informs us about the effects sensory stimulation/deprivation have on the developing brain. We now know that the rapidly growing brains of infants are particularly receptive to sensory experiences – be they ‘good or bad’. The kinds of experiences a child has affects how the brain ‘wires up’, and this in turn impacts upon a child’s future health, learning, and success in life.³

Multisensory stimulation enhances the brains capacity to learn and, with experiences and time, to bundle sensory messages into a single integrated experience of the world.⁶¹ Neonates who received multisensory stimulation (ATV) have shown higher neuromotor scores than those who received standard care in a NICU.⁴⁸ Neuro-motor scores in early infancy have been found to be predictive of later neuro-developmental abnormalities, including cerebral palsy.^{62,63} Furthermore, all modalities of sense – visual, auditory, tactile, vestibular, taste, and smell – provide motor systems with important environmental cues that inform a mode of action.⁶⁴ It is through this dynamic sensorimotor relationship that higher order cognitive states are generated.⁶⁴

Multisensory stimulation is important for all infants, not just those with the potential for, or visible, neurological issues. The challenge is reaching families where resources are poor, mental health is compromised or education limited. Importantly, multisensory stimulation does not need to be a ‘task’ for parents. It is something that can be incorporated into everyday routines of infant care such as bath time, nappy change time, and play time. Delivered with love and implemented through everyday activities, multisensory stimulation builds the foundations for healthy cognitive, physical, social and emotional development.

Expert commentary: Simon Rowley

This is a comprehensive review which nicely encompasses the development of our sensory systems and provides good referencing to support what are often considered as ‘soft’ or non-scientific claims. The research literature is clearly outlined and good examples have been chosen to illustrate the benefits of sensory stimulation. Newborn infants experience the world via their senses – if you like, they are born into a somatosensory bath. Our sensory systems not only play a key role in shaping the brain, they are essential in enabling human infants to experience anything. This may seem obvious, but without any sensory input children simply do not develop. The order in which the senses come on line in brain development seems to be important too and is the same in all species with touch (the ‘mother of all senses’) being the first.

Most NICUs now use this knowledge about the importance of our sensory systems in development, in directing and organizing intensive care for their infants, e.g. attention to muted lighting and sound, timing of handling and procedures, pain relief, and skin to skin contact (kangaroo cuddling). There is good evidence that using such practices can make a difference to subsequent brain development and that these behavioral changes are associated with anatomical brain changes seen on neuro-imaging.⁶⁵

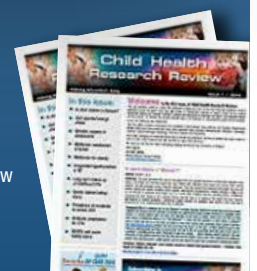
It is important that a reference to sensory overstimulation has been included, i.e. acknowledging that there will be times in an infant’s day when he/she will not be able to cope with too much sensory input and that it may in fact hinder development rather than promote it if continued at these times. The ability to recognize these times is one of the hallmarks of a ‘tuned in’ caregiver.

SUBSCRIBE FREE TO

CHILD HEALTH RESEARCH REVIEW

Child Health Research Review contains an independent selection of papers chosen by a rotating team of medical specialists from the Starship Children’s Hospital discussing what is important in paediatric research and how it can potentially impact current practise.

Time spent reading **Child Health Research Review** has been approved for CME for Royal New Zealand College of General Practitioners and for CNE by The College of Nurses Aotearoa (NZ).



Take-Home Messages

- **Maturation of the brain and sensory systems occurs after birth and is heavily influenced by early life experiences and environmental interactions.**
- **Tactile, auditory, visual, vestibular, and/or olfactory stimulation contributes to the social, emotional, and cognitive development of infants.**
- **Establishment of a consistent nightly bedtime routine that encompasses multisensory stimulation can result in improved night time sleep and fewer sleep problems in infants.**
- **Multisensory stimulation has also been shown to promote maturation of oral feeding in preterm infants and reduce mother and infant stress.**
- **Primary healthcare professionals involved in neonatal and infant care have an important role to play in supporting appropriate sensory development in infants.**

REFERENCES

- Clark-Gambelunghe MB, et al. Sensory development. *Pediatr Clin North Am.* 2015;62(2):367-84.
- Graven SN, et al. Sensory development in the fetus, neonate, and infant: Introduction and overview. *Newborn Infant Nurs Rev.* 2008;8(4):169-72.
- Shonkoff JP and Phillips DK. From neurons to neighbourhoods: The science of early childhood development. 2nd ed. Washington D.C.: National Academy Press. 2000.
- McCain MN, et al. Early years study 2: Putting science into action. Toronto: Council for Early Childhood Development. 2007.
- Lexmond J and Reeves R. Building character: Parents are the principal architects of a fairer society. London: Demos. 2009.
- Fox SE, et al. How the timing and quality of early experiences influence the development of brain architecture. *Child Dev.* 2010;81(1):28-40.
- Kolb B. Brain and behavioural plasticity in the developing brain: Neuroscience and public policy. *Paediatr Child Health.* 2009;14(10):651-2.
- Nelson CA. A neurobiological perspective on early human deprivation. *Child Development Perspectives.* 2007;1(1):13-8.
- World Health Organization. Guidance note for integrating ECD activities into nutrition programmes in emergencies. Why, what, and how? 2014: 1-16. Report No. Available from: http://www.who.int/mental_health/emergencies/ecd_note.pdf
- Moore ER, et al. Early skin-to-skin contact for mothers and their healthy newborn infants. *Cochrane Database Syst Rev.* 2012;5:CD003519.
- Hernandez-Reif M, et al. Preterm infants show reduced stress behaviors and activity after 5 days of massage therapy. *Infant Behav Dev.* 2007;30(4):557-61.
- Diego MA, et al. Vagal activity, gastric motility, and weight gain in massaged preterm neonates. *J Pediatr.* 2005;147(1):50-5.
- Diego MA, et al. Preterm infant massage elicits consistent increases in vagal activity and gastric motility that are associated with greater weight gain. *Acta Paediatr.* 2007;96(11):1588-91.
- Diego MA, et al. Preterm infant weight gain is increased by massage therapy and exercise via different underlying mechanisms. *Early Hum Dev.* 2014;90(3):137-40.
- Field T, et al. Preterm infant massage therapy research: a review. *Infant Behav Dev.* 2010;33(2):115-24.
- Field T. Touch. 2nd ed. Cambridge, Massachusetts: MIT Press. 2014.
- Loewy J, et al. The effects of music therapy on vital signs, feeding, and sleep in premature infants. *Pediatrics.* 2013;131(5):902-18.
- Picciolini O, et al. Early exposure to maternal voice: effects on preterm infants development. *Early Hum Dev.* 2014;90(6):287-92.
- Rand K, et al. Maternal sounds elicit lower heart rate in preterm newborns in the first month of life. *Early Hum Dev.* 2014;90(10):679-83.
- Bremond-Gignac D, et al. Visual development in infants: physiological and pathological mechanisms. *Curr Opin Ophthalmol.* 2011;22 Suppl:S1-8.
- Atkinson J. Human visual development over the first 6 months of life. A review and a hypothesis. *Hum Neurobiol.* 1984;3(2):61-74.
- Farroni T, et al. Eye contact detection in humans from birth. *Proc Natl Acad Sci U S A.* 2002;99(14):9602-5.
- Hyde DC, et al. Visual stimulation enhances auditory processing in 3-month-old infants and adults. *Dev Psychobiol.* 2010;52(2):181-9.
- Herz RS. A naturalistic analysis of autobiographical memories triggered by olfactory visual and auditory stimuli. *Chem Senses.* 2004;29(3):217-24.
- Croy I, et al. Basic emotions elicited by odors and pictures. *Emotion.* 2011;11(6):1331-5.
- Sullivan RM, et al. Olfactory classical conditioning in neonates. *Pediatrics.* 1991;87(4):511-8.
- Landers MS, et al. The development and neurobiology of infant attachment and fear. *Dev Neurosci.* 2012;34(2-3):101-14.
- Marin MM, et al. Two-day-old newborn infants recognise their mother by her axillary odour. *Acta Paediatr.* 2015;104(3):237-40.
- Sullivan RM, et al. Clinical usefulness of maternal odor in newborns: soothing and feeding preparatory responses. *Biol Neonate.* 1998;74(6):402-8.
- Durand K, et al. Eye-catching odors: olfaction elicits sustained gazing to faces and eyes in 4-month-old infants. *PLoS One.* 2013;8(8):e70677.
- Corona R, et al. Chemical olfactory signals and parenthood in mammals. *Horm Behav.* 2015;68:77-90.
- Coffield CN, et al. Adding odor: Less distress and enhanced attention for 6-month-olds. *Infant Behav Dev.* 2014;37(2):155-61.
- Field T, et al. Lavender bath oil reduces stress and crying and enhances sleep in very young infants. *Early Hum Dev.* 2008;84(6):399-401.
- Rattaz C, et al. The calming effect of a familiar odor on full-term newborns. *J Dev Behav Pediatr.* 2005;26(2):86-92.
- Goubet N, et al. Olfactory experience mediates response to pain in preterm newborns. *Dev Psychobiol.* 2003;42(2):171-80.
- Seo HS, et al. Odors enhance visual attention to congruent objects. *Appetite.* 2010;54(3):544-9.
- Jamon M. The development of vestibular system and related functions in mammals: impact of gravity. *Front Integr Neurosci.* 2014;8:11.
- Kaga K, et al. Influence of labyrinthine hypoactivity on gross motor development of infants. *Ann N Y Acad Sci.* 1981;374:412-20.
- Sandler A, et al. Vestibular stimulation in early childhood: A review. *J Early Interv.* 1981;3:48-55.
- Lee HM, et al. Early intensive postural and movement training advances head control in very young infants. *Phys Ther.* 2012;92(7):935-47.
- Guellai B, et al. Cues for early social skills: direct gaze modulates newborns' recognition of talking faces. *PLoS One.* 2011;6(4):e18610.
- Holditch-Davis D, et al. Maternally administered interventions for preterm infants in the NICU: effects on maternal psychological distress and mother-infant relationship. *Infant Behav Dev.* 2014;37(4):695-710.
- Medoff-Cooper B, et al. Multisensory intervention for preterm infants improves sucking organization. *Adv Neonatal Care.* 2015;15(2):142-9.
- Mindell JA, et al. Bedtime routines for young children: a dose-dependent association with sleep outcomes. *Sleep.* 2015;38(5):717-22.
- Mindell JA, et al. A nightly bedtime routine: impact on sleep in young children and maternal mood. *Sleep.* 2009;32(5):599-606.
- White-Traut RC, et al. Effect of auditory, tactile, visual, and vestibular intervention on length of stay, alertness, and feeding progression in preterm infants. *Dev Med Child Neurol.* 2002;44(2):91-7.
- White-Traut RC, et al. Salivary cortisol and behavioral state responses of healthy newborn infants to tactile-only and multisensory interventions. *J Obstet Gynecol Neonatal Nurs.* 2009;38(1):22-34.
- Kanagasabai PS, et al. Effect of multisensory stimulation on neuromotor development in preterm infants. *Indian J Pediatr.* 2013;80(6):460-4.
- Gabis LV, et al. The influence of a multisensory intervention for preterm infants provided by parents, on developmental abilities and on parental stress levels. *J Child Neurol.* 2015;30(7):896-903.
- Unnas-Moberg K, et al. Self-soothing behaviors with particular reference to oxytocin release induced by non-noxious sensory stimulation. *Front Psychol.* 2014;5:1529.
- Bayer JK, et al. Sleep problems in young infants and maternal mental and physical health. *J Paediatr Child Health.* 2007;43(1-2):66-73.
- Teng A, et al. Infant and toddler sleep in Australia and New Zealand. *J Paediatr Child Health.* 2012;48(3):268-73.
- Mindell JA, et al. Behavioral treatment of bedtime problems and night wakings in infants and young children. *Sleep.* 2006;29(10):1263-76.
- Sadeh A, et al. Sleep and sleep ecology in the first 3 years: a web-based study. *J Sleep Res.* 2009;18(1):60-73.
- Morgenthaler T, et al. Practice parameters for the psychological and behavioral treatment of insomnia: an update. An American academy of sleep medicine report. *Sleep.* 2006;29(11):1415-9.
- Dehaene-Lambertz G, et al. Language or music, mother or Mozart? Structural and environmental influences on infants' language networks. *Brain Lang.* 2010;114(2):53-65.
- Als H, et al. The Newborn Individualized Developmental Care and Assessment Program (NIDCAP) with Kangaroo Mother Care (KMC): Comprehensive Care for Preterm Infants. *Curr Womens Health Rev.* 2011;7(3):288-301.
- Aucott S, et al. Neurodevelopmental care in the NICU. *Ment Retard Dev Disabil Res Rev.* 2002;8(4):298-308.
- Linn PL, et al. Stimulation in the NICU: is more necessarily better? *Clin Perinatol.* 1985;12(2):407-22.
- Piaget J. Origins of intelligence in the child. London: Routledge & Kegan Paul. 1936.
- Stein BE and Meredith MA. The Merging of the Senses. Cambridge, MA: MIT Press. 1993.
- Einspieler C, et al. Prechtl's assessment of general movements: a diagnostic tool for the functional assessment of the young nervous system. *Ment Retard Dev Disabil Res Rev.* 2005;11(1):61-7.
- Prechtl HF, et al. An early marker for neurological deficits after perinatal brain lesions. *Lancet.* 1997;349(9062):1361-3.
- Delafield-Butt JT, et al. Sensorimotor intentionality: The origins of intentionality in prospective action. *Dev Rev.* 2013;33(4):399-425.
- Als H, et al. Early experience alters brain function and structure. *Pediatrics.* 2004;113(4):846-57.