

Research Review

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Multi-sensory stimulation and infant development

About the Experts



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The focus of this review is the science of sensory development and stimulation in neonates and infants, especially 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 development.

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, 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} For example, home-based developmental interventions during the first three years of life have been demonstrated to benefit cognitive development, including in children living in rural areas of India and Pakistan and in children from low- to middle-resource families.^{6,7} In addition, early intervention programmes for pre term infants produce beneficial cognitive outcomes during infancy and persisting into childhood.⁸

Moreover, early life experiences influence gene expression, which in turn determines brain architecture.⁹ Early life experiences also shape the development of lower level neural circuits upon which higher level circuits (that are responsible for more sophisticated mental functions) are dependent for the input of precise and high-quality information (**Figure 1**).^{3,9} Low birth-weight infants have been shown to be at particularly high risk of neurosensory deficit and failure to thrive.¹⁰

The major influence that early life experiences and external stimuli have on brain and sensory system development underscores the important role of sensory stimulation in facilitating infant growth and development.

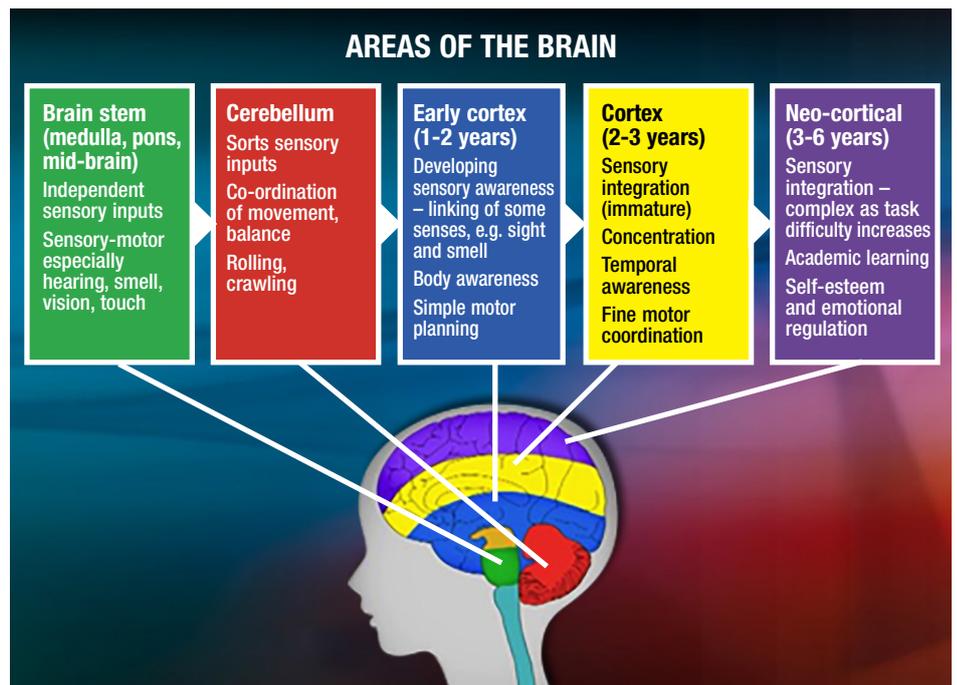


Figure 1. Sensory systems develop with time, experience, and brain maturation and higher level brain development is dependent on lower level development.^{1-3,9}

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.¹¹ Maturing physiological, biochemical, and psychological functions are affected by touch.¹² The importance of tactile stimulation is emphasised by the WHO recommendation to provide skin-to-skin contact starting at birth to facilitate child development.¹³

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.¹⁴

Infant massage is a traditional practice on the Indian subcontinent, with the potential benefits including weight gain, a better sleep-wake pattern, improved neuromotor development, and enhanced emotional bonding.¹⁵ Studies by Indian researchers have demonstrated that massage, mostly with oil, has benefits on growth in preterm and term infants,¹⁶⁻²⁰ with one randomized study suggesting that massage with oil produces greater growth benefits than massage without oil.¹⁷ However, it is important to be aware that some oils can have a detrimental effect on neonatal skin barrier structure and function.^{21,22}

In preterm infants, randomised controlled studies have shown that skin-to-skin contact via moderate-pressure massage can reduce stress behaviours in preterm infants²³ and facilitate weight gain.²⁴⁻²⁶ Increased vagal activity, gastric motility, and insulin levels following moderate-pressure massage are possible mechanisms underlying the observed weight gain in preterm infants.²⁷

Tactile stimulation is important throughout infancy as evidenced by developmental deficits in children raised in environments in which they were deprived of touch.²⁸

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. 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.²⁹⁻³¹ Maternal sounds were also associated with improved feeding behaviours and enhanced mother-infant bonding, thereby reducing parental stress associated with pre term infant care.²⁹

Visual sense (sight)

Vision is poorly developed at birth but matures rapidly with stimulation in the first few months of life.^{32,33} Maturation of the visual system, including neurological and ocular components, is influenced by many factors including prenatal and postnatal nutrition and postnatal visual stimulation.³³ The visual cortex is the part of the brain responsible for processing visual information.³²

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.³⁴ Indeed, the WHO recommends that parents should engage in direct eye contact with their infant starting at birth.¹³ This early sensitivity to mutual gaze is likely to support the development of social skills later in life.³⁴ Visual stimulation also appears to enhance auditory processing in infants.³⁵

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,³⁶ with the specific emotions able to be elicited through the olfactory pathway being happiness, disgust, and anxiety.³⁷ It has also been shown that, in neonates, learning is enhanced when olfactory stimulation is combined with tactile stimulation.³⁸

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.^{1,39} 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.³⁹ As early as 2-days-old, complex associative olfactory learning is observed in newborns³⁸ and infants who experience skin-to-skin contact with their mothers are able to recognize their own mother's axillary odour.⁴⁰ 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.⁴¹ In another study, infants' social attention to faces was enhanced in the presence of maternal odour.⁴² 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. Also, just as there is evidence that infants can identify their mother's odour, there is also evidence that mothers can identify their infant's odour.⁴³ 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.⁴⁴⁻⁴⁶ Familiarity of odour (whether maternal or other) may be a factor in the calming effects of odours in infants.^{46,47} For example, presentation of a familiar odour (e.g. vanilla) to infants during a minor painful procedure (heel prick or venipuncture) was associated with less crying relative to infants presented with an unfamiliar or no odour during venipuncture.⁴⁷

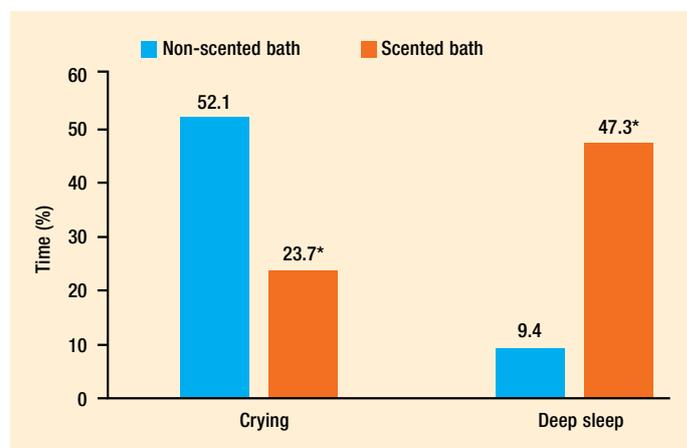


Figure 2. Post-bath behavior (percentage of time crying and in deep sleep) in infants bathed with lavender-scented bath oil (n=10) versus infants bathed with unscented bath oil (n=10) in a randomised study.⁴⁵ $p < 0.05$ versus unscented bath.

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.⁴⁵ 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. 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**).

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,⁴⁴ and the presence of maternal odour to increase an infant's attention (looking time) to faces and eyes.⁴² These findings are supported by the observation in adults that odour enhances attention towards visual objects congruent with that odour.⁴⁸ It is suggested that these results have implications for optimizing infant environments for and cognitive development.⁴⁴

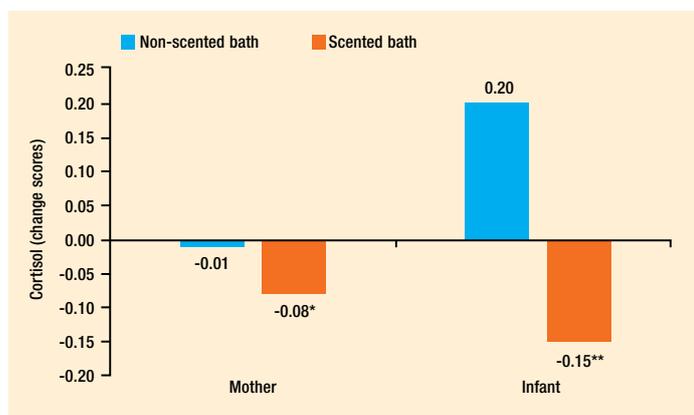


Figure 3. Relaxation measured as salivary cortisol levels in infants ($n=10$) and their mothers ($n=10$) after bathing the infants using lavender-scented bath oil in a randomized study.⁴⁵ * $p < 0.05$ versus unscented bath; ** $p < 0.005$ versus unscented bath

Vestibular sense (balance and movement)

The vestibular structures are morphologically well developed at birth but continue to develop during the first post-natal month.⁴⁹ 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. Indeed, there is accumulating evidence that vestibular dysfunction may delay the achievement of head control and independent walking in infants.⁵⁰ The vestibular system may also be involved in regulating the autonomic system, including arterial pressure regulation and bone mineralisation.⁴⁹

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.⁵¹ As an example of vestibular stimulation 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.⁵²

Furthermore, there is clinical study evidence that, presumably by inducing a calm or sleeping state, vestibular stimulation in the form of rocking before an acutely painful procedure can ameliorate pain behaviours in neonates.⁵³ For example,

in a randomized controlled study, Mathai et al. showed that rocking was more effective than massage in reducing crying and pain scores in neonates requiring a heel prick.⁵⁴

Multisensory stimulation

A large evidence base exists that supports the association of multisensory stimulation (also known as multimodal sensory 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.⁵⁵⁻⁶³ For example, multisensory stimulation in preterm infants has been demonstrated to improve language and motor skills at age 2 to 3 years.⁵⁵ Another example of multisensory stimulation is the demonstration that gaze and infant-directed speech experienced together stimulate the development of early social skills.⁵⁶ 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.

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).^{61,62} 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,^{58,61} and to increase alertness and reduce the duration of hospitalisation⁶¹ 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.^{58,61} 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.⁵⁷

The underlying benefit of multisensory stimulation may be in the reduction of infant stress. 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.⁵⁷ This is a desirable effect given the potential for stress to negatively affect brain development.¹¹ 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.⁶²

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.⁶⁴ 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.

Another potential benefit of the ATVV intervention is a positive effect on neuromotor development. Feeding problems in preterm infants have been demonstrated to be significantly associated with early hypotonia.⁶⁵ In a randomised controlled study, multisensory stimulation via the ATVV intervention facilitated tonal maturation in preterm infants.⁶³

Kangaroo mother care

Kangaroo mother care (KMC), which is a common form of infant nurture, is inherently multisensory. It provides tactile stimulation through skin-to-skin contact, olfactory-gustatory stimulation via breastfeeding, olfactory stimulation through being in close proximity to the mother's odour, and auditory stimulation by way of the mother's voice.⁶⁶

A meta-analysis of studies indicates that KMC reduces mortality and morbidity in infants, including beneficial effects on some measures of infant growth and facilitation of mother-infant bonding.⁶⁷ Although its effects on neurodevelopment have not been well researched, a recent 20-year follow-up study in low-birth weight infants has demonstrated long-lasting positive effects of KMC on neurologic, cognitive, and social functioning.⁶⁸

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.

Epidemiological studies suggest that 20-30% of infants and toddlers experience problems sleeping.⁶⁹⁻⁷² There is also considerable evidence that behavioural interventions for the treatment of sleep problems in children are efficacious, including a bedtime routine as a part of a multicomponent treatment programme.^{71,73} 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.⁶⁰ 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.

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^{34,35}), auditory (mother's voice⁷⁴), and olfactory (familiar scents – that of the mother⁴¹ and/or the bath products used⁴⁵) senses.

In the infant cohort, the pre-bedtime routine resulted in significant ($p < 0.001$) reductions in the number and duration of night waking (Figure 4) and in time to sleep onset compared with baseline.⁶⁰ 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.

These findings are supported by those of a large multinational study that recruited 10,085 mothers from 14 countries, including India.⁵⁹ 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.

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, both of which are incompatible with the developing nervous system's expectations during a sensitive time of brain development.^{75,76}

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.^{75,77}

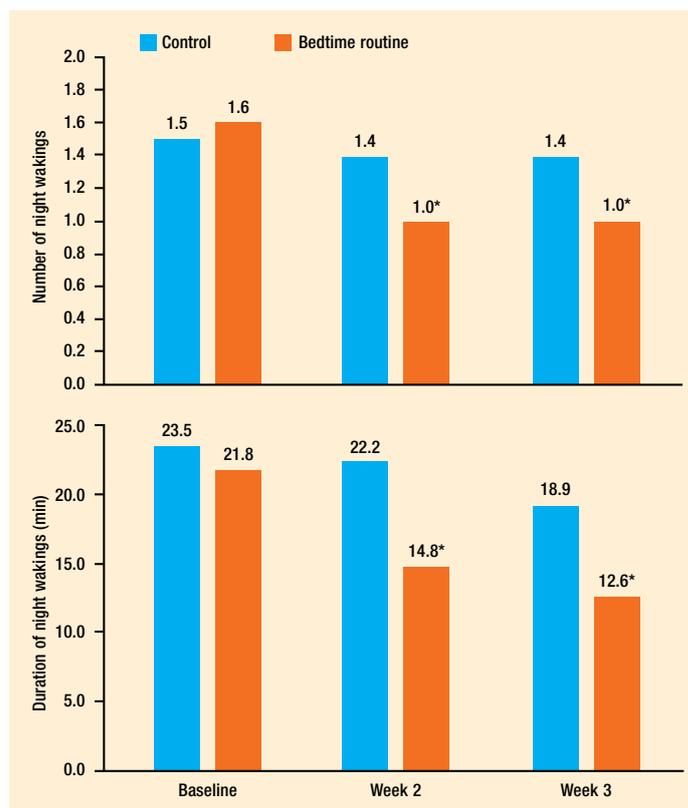


Figure 4. Number and duration of night wakings in infants (n=206) following a consistent bedtime routine.⁶⁰ * $p < 0.001$ versus baseline

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EXPERT COMMENTARY: SWATI POPAT VATS

The article concretely summarizes the importance of infant multisensory stimulation and lays a much-needed emphasis on the concurrent stimulation of auditory, tactile, visual, vestibular, and olfactory senses. The impact of such multisensory stimulation has long-term benefits on social, emotional, cognitive, and physical development that are clearly evident up to age 2 to 3 years and beyond. Young parents of infants are usually focused on toileting and feeding needs and tend to ignore the importance or relevance of these early multisensory stimulations and this article provides evidence that these experiences relate to the child's future success socio-emotionally and academically.

In India, and many other countries, there is very little emphasis on home-based developmental interventions and this article clearly outlines not only the potential benefits but also how each of the senses can be involved in multisensory infant stimulation. I highly recommend that this should be given to every new mother whether in urban or rural settings so that both parents can understand science-based reasons behind common cultural practices

such as having eye contact while feeding or talking to a baby or having skin-to-skin contact during breast feeding or daily infant massage. All are linked to potential benefits including weight gain, a better sleep-wake pattern, improved neuromotor development, and enhanced emotional bonding.

Another important point in the article is the research related to olfactory stimulation and its impact on emotional processing. Parents and caregivers in daycare centres can benefit hugely by ensuring that an infant's stimulation includes olfactory stimulation with tactile stimulation; for example, using a vanilla/lavender-based massage oil or lavender-scented baths. Infants are rocked and sung to in all cultures and this article helps label this casual everyday activity as vestibular stimulation that enhances visual alertness, visual tracking behavior, and motor and reflex development in infants.

It is also important for parents and caregivers to understand from the research in this article that the underlying benefit of multisensory stimulation is the reduction of infant stress.

EXPERT COMMENTARY: NANDINI MUNDKUR

The importance of brain development in early years and the factors influencing it are best understood by the transactional model by Sameroff and Chandler.⁷⁸ To quote: "At birth, a child's biological endowment includes sensory, motor, and neurological capacities intact or impaired for organising experience and interacting with the environment." This model assumes that the infant, caregiver, and environment determine a child's development and behaviour. This is supported by research on brain development, which shows that caregiving and social factors mediated by the sensory system and genetic influences shape the developing brain architecture associated with the changes in development and behaviour. An enriched environment ensures growth and maintenance of synaptic connections during early development when the central neural connections are formed rapidly and unused connections are pruned. Stressful experiences can result in neurochemical changes that can lead to structural changes in the brain.

In this context, we can appreciate the advantages a child can gain if it receives proper stimulation of the sensory system.

There are traditional practices in India, and a few other countries, of considering the first 49 days of motherhood as a valuable time for her to bond with her infant. Traditionally, this period is meant to give her the privilege and support to slowly and respectfully recover from birthing, and enjoy a cozy time building a loving relationship with her newborn. This confinement period has been traditionally a part of several cultures around the world including our own rich Indian culture and is still widely practiced throughout Asia and few

other parts of the world. Be it 'Zouyuzei' in the Chinese culture, 'kyrkynan shygaru' in the Kazakh culture, or 'cuarentena' in parts of Latin America, even though the customs and exact duration may differ, all are aimed at protecting the new mother and the newborn baby. This confinement period, where the mother has the luxury to spend all her time with her baby, is equally crucial for the baby's social, sensory, and cognitive development, which begins with understanding and recognising the mother's voice, touch, smell, and face/expressions. Several activities such as rocking the baby, singing lullabies, speaking to the baby while feeding on the breast, the mother wearing a big red bindi on the forehead perhaps to help the baby focus on her face, and tying a hammock with the mother's soft saree are some of the activities to encourage this bonding.

The time spent together will also enable the mother to notice any early signs of delay or deviance in the baby's development. Considering all the above, it may be wise to encourage this traditional practice in new moms everywhere. The following are some of the red flags to watch for in a newborn child during the first few weeks:

- Lethargy.
- Lack of interaction.
- No response to loud noise.
- Trouble moving the eyes or following moving objects.
- Quivering lower jaw.

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.**

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