**PRESENT SENSORY OPPORTUNITIES**

This section includes articles from the literature on specific sensory processing, and outcomes of enriched environments (both human and animal literature are included).

**Korholz, J., Zocher, S., Grzyb, A. N., Morisse, B., Poetzsch, A., Ehret, F., ... & Kempermann, G. (2018). Selective increases in inter-individual variability in response to environmental enrichment. *bioRxiv*, 260455.**

One manifestation of individualization is a progressively differential response of individuals to the non-shared components of the same environment. Individualization has practical implications in clinical setting, where subtle differences between patients are often decisive for the success of an intervention, yet there has been no suitable animal model to study its underlying biological mechanisms. Here we show that enriched environment (ENR) can serve as a model of brain individualization. We kept 40 isogenic mice for 3 months in ENR and compared the effects on a wide range of phenotypes on both mean and variance to an equally sized group of standard-housed control animals. While ENR influenced multiple parameters and restructured correlation patterns between them, it only increased differences among individuals in traits related to brain and behavior (adult hippocampal neurogenesis, motor cortex thickness, open field and object exploration, rotarod performance), in agreement with the hypothesis of a specific activity-dependent development of brain individuality.

**Wang, R., Hausknecht, K. A., Haj-Dahmane, S., Shen, R., & Richards, J. B. (2018). Decreased environmental complexity during development impairs habituation of reinforcer effectiveness of sensory stimuli. *Behavioural Brain Research,* *337*, 53-60. doi:10.1016/j.bbr.2017.09.032**

Previous research has shown that rats reared in simple/impoverished environments demonstrate greater repetitive responding for sensory reinforcers (e.g., light onset). Moreover, the brains of these rats are abnormally developed, compared to brains of rats reared in more complex/enriched environments. Repetitive behaviors are commonly observed in individuals with developmental disorders. Some of these repetitive behaviors could be maintained by the reinforcing effects of the sensory stimulation that they produce. Therefore, rearing rats in impoverished conditions may provide an animal model for certain repetitive behaviors associated with developmental disorders. We hypothesize that in rats reared in simple/impoverished environments, the normal habituation process to sensory reinforcers is impaired, resulting in high levels of repetitive behaviors. We tested the hypothesis using an operant sensory reinforcement paradigm in rats reared in simple/impoverished (IC), standard laboratory (SC), and complex/enriched conditions (EC, treatments including postnatal handling and environmental enrichment). Results show that the within-session habituation of the reinforcer effectiveness of light onset was slower in the IC and SC rats than in the EC rats. A dishabituation challenge indicated that within-session decline of responses was due to habituation and not motor fatigue or sensory adaptation. In conclusion, rearing rats in simple/impoverished environments, and comparing them to rats reared in more complex/enriched environments, may constitute a useful approach for studying certain repetitive behaviors associated with developmental disorders.

**Dolivo, V., & Taborsky, M. (2017). Environmental enrichment of young adult rats (Rattus norvegicus) in different sensory modalities has long-lasting effects on their ability to learn via specific sensory channels. *Journal of Comparative Psychology,* *131*(2), 79-88. doi:10.1037/com0000063**

Sensory modalities individuals use to obtain information from the environment differ among conspecifics. The relative contributions of genetic divergence and environmental plasticity to this variance remain yet unclear. Numerous studies have shown that specific sensory enrichments or impoverishment at the postnatal stage can shape neural development, with potential lifelong effects. For species capable of adjusting to novel environments, specific sensory stimulation at a later life stage could also induce specific long-lasting behavioral effects. To test this possibility, we enriched young adult Norway rats with either visual, auditory, or olfactory cues. Four to 8 months after the enrichment period we tested each rat for their learning ability in 3 two-choice discrimination tasks, involving either visual, auditory, or olfactory stimulus discrimination, in a full factorial design. No sensory modality was more relevant than others for the proposed task per se, but rats performed better when tested in the modality for which they had been enriched. This shows that specific environmental conditions encountered during early adulthood have specific long-lasting effects on the learning abilities of rats. Furthermore, we disentangled the relative contributions of genetic and environmental causes of the response. The reaction norms of learning abilities in relation to the stimulus modality did not differ between families, so interindividual divergence was mainly driven by environmental rather than genetic factors.

**2016**

**Hong, S. L., Estrada-Sánchez, A. M., Barton, S. J., & Rebec, G. V. (2016). Early exposure to dynamic environments alters patterns of motor exploration throughout the lifespan. *Behavioural brain research*, *302*, 81-87.**

We assessed early rearing conditions on aging-related changes in mouse behavior. Two isolated-housing groups, running wheel (IHRW) and empty cage (IHEC), were compared against two enriched environments, static (EEST) and dynamic (EEDY), both of which included toys and other mice. For EEDY, the location of toys and sources of food and water changed daily, but remained constant for EEST. All mice, randomly assigned to one of the four groups at ∼4 weeks of age, remained in their respective environments for 25 weeks followed by single housing in empty cages. Beginning at ∼40 weeks of age, all mice were tested at monthly intervals in a plus-shaped maze in which we measured the number of arm entries and the probability of entering a perpendicular arm. Despite making significantly more arm entries than any other group, IHEC mice also were less likely to turn into the left or right arm, a sign of motor inflexibility. Both EEDY and EEST mice showed enhanced turning relative to IHRW and IHEC groups, but only EEDY mice maintained their turning performance for up to ∼100 weeks of age. EEDY and EEST mice also were unique in showing an increase in expression of the major glutamate transporter (GLT1) in striatum, but a decrease in motor cortex, suggesting a need for further assessment of environmental manipulations on long-term changes in forebrain glutamate transmission. Our behavioral results indicate that early exposure to continually changing environments, rather than socialization or exercise alone, results in life-long changes in patterns of motor exploration.

**Hua, J., Duan, T., Gu, G., Wo, D., Zhu, Q., Liu, J. Q., ... & Meng, W. (2016). Effects of home and education environments on children's motor performance in China. *Developmental Medicine & Child Neurology*.**

**Purpose**:The aim of this study was to examine the effects of home and educational environments on children's motor performance in China.

### Methods:We conducted a cross-sectional study of 4001 preschool children selected from 160 classes. The children's motor performance was assessed using the Movement Assessment Battery for Children, 2nd edition (MABC-2). Home and educational environments were evaluated using validated checklists. The effects of home and educational environments on motor performance were analysed using mixed and multilevel logistic regression models.

### Results: The results showed that one score increase in the outside space of the family home was positively associated with the increase in total test score (0.104) subtest score of aiming and catching (0.037), and balance (0.034) of the MABC-2, after adjusting for potential confounders (each *p*<0.05). Possession of motor toys at home and parental rearing behaviours were also related to total test score, manual dexterity, and balance (*β*=0.022–0.104, each *p*<0.05). Space and furnishings, activity, and interaction in the classroom had a significant positive association with total test score (*β*=0.069–0.201), and with subtest scores of manual dexterity, aiming and catching, and balance respectively (*β*=0.115–0.206). Space and furnishings of classrooms and possession of toys in the household were protective factors for ‘at risk’ or significant poor performance (odds ratio 0.942–0.973, each *p*<0.05).

### Interpretation: A permissive and accepting family and educational environment made a positive contribution to children's motor performance. Access to sufficient space and furnishings within the classroom, as well as toys in the family, were protective factors for poor motor performance. Future assistance is needed to support an advantageous environment in early childhood programmes in China.

**Lambert, K., Hyer, M., Bardi, M., Rzucidlo, A., Scott, S., Terhune-Cotter, B., ... & Kinsley, C. (2016). Natural-enriched environments lead to enhanced environmental engagement and altered neurobiological resilience. *Neuroscience*, *330*, 386-394.**

The mammalian brain has evolved in close synchrony with the natural environment; consequently, trends toward disengagement from natural environments in today’s industrialized societies may compromise adaptive neural responses and lead to psychiatric illness. Investigations of rodents housed in enriched environments indicate enhanced neurobiological complexity; yet, the origin of these stimuli, natural vs. manufactured, has not been sufficiently explored. In the current study, groups of rats were exposed to one of three environments: (1) a standard environment with only food and water, (2) an artificial-enriched environment with manufactured stimuli and (3) a natural-enriched environment with natural stimuli. Results indicated that, during the dark phase, natural-enriched animals exhibited longer durations interacting with objects than the artificial-enriched group; further, the natural-enriched group engaged in more social behavior than the other two groups. Both enriched groups exhibited less anxiety in response to a novel object but the natural-enriched rats exhibited less anxiety-typical behavior in response to a predator odor than the other groups. Less fos activation in the amygdala was observed in both enriched groups following a water escape task whereas an increase in fos activation in the nucleus accumbens was observed in the natural-enriched animals. Thus, the current findings indicate the potential importance of exposure to complex environments, especially natural-like habitats, in the maintenance of emotional health, perhaps providing a buffer against the emergence of anxiogenic responses.

**2015**

**Cárdenas, L., García-García, F., Santiago-Roque, I., Martínez, A. J., Coria-Ávila, G. A., & Corona-Morales, A. A. (2015). Enriched environment restricted to gestation accelerates the development of sensory and motor circuits in the rat pup. *International Journal of Developmental Neuroscience*, *41*, 68-73.**

The effects of stimulating environments on the [neural plasticity](http://topics.sciencedirect.com/topics/page/Neuroplasticity) of the adult brain have been well explored; however, how an enriched environment (EE) affects the mother-fetus interaction is poorly understood. We hypothesized that an enriched environment restricted to pregnancy will succeed in accelerating the development of sensory and motor circuits in the offspring. Pregnant Wistar rats were maintained either under a standard condition – two animals per standard cage- or an enriched environment – eight subjects in larger cages with different physical configurations-. After birth, litters from both groups (*n* = 16 per group) were [cross-fostered](http://topics.sciencedirect.com/topics/page/Cross-fostering) with mothers that were simultaneously maintained under standard environment during pregnancy. Sensory and [motor development](http://topics.sciencedirect.com/topics/page/Motor_neuron) were studied in the pups of both groups with a battery of reflex and physical tests. Auditory and [gait](http://topics.sciencedirect.com/topics/page/Gait) reflexes appeared two days earlier in the offspring of EE rats as compared to control subjects (*p* < 0.05). In addition, EE pups displayed a better performance in righting reflex, inclined board and geotaxis tests (*p* < 0.05). Differences were found even three weeks after birth. We conclude that EE limited to the phase of pregnancy stimulates the development of pups *in utero* so that they are born with a higher grade of development.

**Cignetti, F., Fontan, A., Menant, J., Nazarian, B., Anton, J. L., Vaugoyeau, M., & Assaiante, C. (2016). Protracted development of the proprioceptive brain network during and beyond adolescence. *Cerebral Cortex*, bhv323.**

Proprioceptive processing is important for appropriate motor control, providing error-feedback and internal representation of movement for adjusting the motor command. Although proprioceptive functioning improves during childhood and adolescence, we still have few clues about how the proprioceptive brain network develops. Here, we investigated developmental changes in the functional organization of this network in early adolescents (n = 18, 12 ± 1 years), late adolescents (n = 18, 15 ± 1), and young adults (n = 18, 32 ± 4), by examining task-evoked univariate activity and patterns of functional connectivity (FC) associated with seeds placed in cortical (supramarginal gyrus) and subcortical (dorsal rostral putamen) regions. We found that although the network is already well established in early adolescence both in terms of topology and functioning principles (e.g., long-distance communication and economy in wiring cost), it is still undergoing refinement during adolescence, including a shift from diffuse to focal FC and a decreased FC strength. This developmental effect was particularly pronounced for fronto-striatal connections. Furthermore, changes in FC features continued beyond adolescence, although to a much lower extent. Altogether, these findings point to a protracted developmental time course for the proprioceptive network, which breaks with the relatively early functional maturation often associated with sensorimotor networks.

**Carriot, J., Jamali, M., & Cullen, K. E. (2015). Rapid adaptation of multisensory integration in vestibular pathways. *Frontiers in systems neuroscience*, *9*.**

Sensing gravity is vital for our perception of spatial orientation, the control of upright posture, and generation of our everyday activities. When an astronaut transitions to microgravity or returns to earth, the vestibular input arising from self-motion will not match the brain's expectation. Our recent neurophysiological studies have provided insight into how the nervous system rapidly reorganizes when vestibular input becomes unreliable by both (1) updating its internal model of the sensory consequences of motion and (2) up-weighting more reliable extra-vestibular information. These neural strategies, in turn, are linked to improvements in sensorimotor performance (e.g., gaze and postural stability, locomotion, orienting) and perception characterized by similar time courses. We suggest that furthering our understanding of the neural mechanisms that underlie sensorimotor adaptation will have important implications for optimizing training programs for astronauts before and after space exploration missions and for the design of goal-oriented rehabilitation for patients.

**Reichenbach, A., Bresciani, J. P., Bülthoff, H. H., & Thielscher, A. (2016). Reaching with the sixth sense: Vestibular contributions to voluntary motor control in the human right parietal cortex. *NeuroImage*, *124*, 869-875.**

The [vestibular system](http://topics.sciencedirect.com/topics/page/Vestibular_system) constitutes the silent sixth sense: It automatically triggers a variety of vital reflexes to maintain postural and visual stability. Beyond their role in reflexive behavior, [vestibular](http://topics.sciencedirect.com/topics/page/Vestibular) afferents contribute to several perceptual and cognitive functions and also support voluntary control of movements by complementing the other senses to accomplish the movement goal. Investigations into the neural correlates of vestibular contribution to voluntary action in humans are challenging and have progressed far less than research on corresponding visual and [proprioceptive](http://topics.sciencedirect.com/topics/page/Proprioception) involvement. Here, we demonstrate for the first time with event-related [TMS](http://topics.sciencedirect.com/topics/page/Transcranial_magnetic_stimulation) that the posterior part of the right medial [intraparietal sulcus](http://topics.sciencedirect.com/topics/page/Intraparietal_sulcus) processes vestibular signals during a goal-directed reaching task with the dominant right hand. This finding suggests a qualitative difference between the processing of vestibular vs. visual and proprioceptive signals for controlling voluntary movements, which are pre-dominantly processed in the left [posterior parietal cortex](http://topics.sciencedirect.com/topics/page/Posterior_parietal_cortex). Furthermore, this study reveals a neural pathway for vestibular input that might be distinct from the processing for reflexive or cognitive functions, and opens a window into their investigation in humans.

**Hiemstra, D., & Van Yperen, N. W. (2015). The effects of strength-based versus deficit-based self-regulated learning strategies on students’ effort intentions. *Motivation and emotion*, *39*(5), 656-668.**

In two randomized experiments, one conducted online (*n* = 174) and one in the classroom (*n* = 267), we tested the effects of two types of self-regulated learning (SRL) strategies on students’ intentions to put effort into professional development activities: *strength*-*based SRL strategies* (i.e., identifying perceived relative strengths and, subsequently, selecting professional development activities to further improve those strengths) versus *deficit*-*based SRL strategies* (i.e., identifying perceived relative shortcomings and, subsequently, selecting professional development activities to improve those shortcomings). Across both studies, analysis of variance revealed that, relative to students who used deficit-based SRL strategies, students who used strength-based SRL strategies were higher in perceived competence, intrinsic motivation, and effort intentions. Moreover, the results of multi-mediator analysis and structural equation modeling supported the hypothesis that the effect of strength-based versus deficit-based SRL strategies on students’ effort intentions was sequentially mediated by perceived competence and intrinsic motivation. Implications for the application of self-regulated learning strategies in the context of professional self-development are discussed.

**Karpati, F. J., Giacosa, C., Foster, N. E., Penhune, V. B., & Hyde, K. L. (2015). Sensorimotor integration is enhanced in dancers and musicians. *Experimental brain research*, 1-11.**

Studying individuals with specialized training, such as dancers and musicians, provides an opportunity to investigate how intensive practice of sensorimotor skills affects behavioural performance across various domains. While several studies have found that musicians have improved motor, perceptual and sensorimotor integration skills compared to untrained controls, fewer studies have examined the effect of dance training on such skills. Moreover, no study has specifically compared the effects of dance versus music training on perceptual or sensorimotor performance. To this aim, in the present study, expert dancers, expert musicians and untrained controls were tested on a range of perceptual and sensorimotor tasks designed to discriminate performance profiles across groups. Dancers performed better than musicians and controls on a dance imitation task (involving whole-body movement), but musicians performed better than dancers and controls on a musical melody discrimination task as well as on a rhythm synchronization task (involving finger tapping). These results indicate that long-term intensive dance and music training are associated with distinct enhancements in sensorimotor skills. This novel work advances knowledge of the effects of long-term dance versus music training and has potential applications in therapies for motor disorders.

**2014**

**Herms J., Jung CKE. (2014). Structural dynamics of dendritic spines are influenced by an environmental enrichment: An in vivo imaging study. *Cerebral Cortex, 24*(2), 377-384.** **doi: 10.1093/cercor/bhs317.**

Sensory experience alters neuronal circuits, which is believed to form the basis for learning and memory. On a microscopic level, structural changes of the neuronal network are prominently observable as experience-dependent addition and removal of cortical dendritic spines. By environmental enrichment, we here applied broad sensory stimulation to mice and followed the consequences to dendritic spines in the somatosensory cortex utilizing in vivo microscopy. Additionally to apical dendrites of layer V neurons, which are typically analyzed in in vivo imaging experiments, we investigated basal dendrites of layer II/III neurons and describe for the first time experience-dependent alterations on this population of dendrites. On both classes of cortical dendrites, enriched environment-induced substantial changes determined by increases in density and turnover of dendritic spines. Previously established spines were lost after enriched stimulation. A fraction of experience-induced gained spines survived for weeks, which might therefore be functionally integrated into the neuronal network. Furthermore, we observed an increased density of spines that appeared only transiently. Together, we speculate that the cognitive benefits seen in environmental-enriched animals might be a consequence of both, a higher connectivity of the neuronal network due to more established synapses and an enhanced flexibility due to more transient spines.

**2013**

**Alwis, D.S. & Rajan, R. (2013). Environmental enrichment causes a global potentiation of neuronal responses across stimulus complexity and lamina of sensory cortex. *Front Cell Neurosci, 7*, 124.**

Enriched social and physical housing produces many molecular, anatomical, electrophysiological and behavior benefits even in adult animals. Much less is known of its effects on cortical electrophysiology, especially in how sensory cortex encodes the altered environment, and extant studies have generally been restricted to neurons in input laminae in sensory cortex. To extend the understanding of how an enriched environment alters the way in which cortex views the world, we investigated enrichment-induced changes in neuronal encoding of sensory stimuli across all laminae of the rat barrel cortex receiving input from the face whisker tactile system. Animals were housed in Enriched (*n* = 13) or Isolated housing (*n* = 13) conditions for 8 weeks before extracellular recordings were obtained from barrel cortex in response to simple whisker deflections and whisker motions modeling movements seen in awake animals undertaking a variety of different tasks. Enrichment resulted in increases in neuronal responses to all stimuli, ranging from those modeling exploratory behavior through to discrimination behaviors. These increases were seen throughout the cortex from supragranular layers through to input Layer 4 and for some stimuli, in infragranular Layer 5. The observed enrichment-induced effect is consistent with the postulate that enrichment causes shift in cortical excitatory/inhibitory balance, and we demonstrate this is greatest in supragranular layers. However, we also report that the effects are non-selective for stimulus parameters across a range of stimuli except for one modeling the likely use of whiskers by the rats in the enriched housing.

**2011**

**Halperin, J.M. & Healey, D.M. (2011). The influences of environmental enrichment, cognitive enhancement, and physical exercise on brain development: Can we alter the developmental trajectory of ADHD? *Neuroscience & Biobehavioral Reviews, 35*, 621-634. 10.1016/j.neubiorev.2010.07.006.**

Attention-deficit/Hyperactivity Disorder (ADHD) is characterized by a pervasive pattern of developmentally inappropriate inattentive, impulsive and hyperactive behaviors that typically begin during the preschool years and often persist into adulthood. The most effective and widely used treatments for ADHD are medication and behavior modification. These empirically-supported interventions are generally successful in reducing ADHD symptoms, but treatment effects are rarely maintained beyond the active intervention. Because ADHD is now generally thought of as a chronic disorder that is often present well into adolescence and early adulthood, the need for continued treatment throughout the lifetime is both costly and problematic for a number of logistical reasons. Therefore, it would be highly beneficial if treatments would have lasting effects that remain after the intervention is terminated. This review examines the burgeoning literature on the underlying neural determinants of ADHD along with research demonstrating powerful influences of environmental factors on brain development and functioning. Based upon these largely distinct scientific literatures, we propose an approach that employs directed play and physical exercise to promote brain growth which, in turn, could lead to the development of potentially more enduring treatments for the disorder.

**Francesca Gelfo, Debora Cutuli, Francesca Foti, Daniela Laricchiuta, Paola De Bartolo Carlo Caltagirone, Laura Petrosini, and Francesco Angelucci (2011). Enriched environment improves motor function and increases neurotrophins in hemi-cerebellar lesioned rats *Neurorehabil Neural Repair 25: 243-252.* doi:10.1177/1545968310380926**

**Background:** Environmental enrichment (EE) defined as “a combination of complex inanimate and social stimulation” influences brain function and anatomy by enhancing sensory, cognitive, motor, and social stimulation. The beneficial effects of EE in the presence of brain damage have been partially attributed to upregulation of neurotrophins, proteins involved in neuronal survival and in activity-dependent plasticity. **Objective**:The authors tested the hypothesis that EE may have advantageous effects on recovery of motor function after cerebellar damage, associated with changes in local neurotrophin production.

**Methods**: They performed a hemi-cerebellectomy in rats previously exposed to EE or reared in standard conditions. The time course of compensation of motor symptoms was analyzed in both lesioned groups. Then, the local production of the nerve growth factor (NGF) and brain-derived neurotrophic factor (BDNF) in the spared hemi-cerebellum and other extra-cerebellar regions was evaluated.

**Results**: Long-term exposure to EE accelerated the motor recovery in hemicerebellectomized rats and elicited an increase in NGF levels in the spared hemi-cerebellum, as compared with non-enriched lesioned and control rats. BDNF levels were higher in hemicerebellectomized rats but not influenced by EE. In the frontal cortex, both NGF and BDNF levels were upregulated in hemi-cerebellectomized enriched rats as compared with hemicerebellectomized non-enriched and control rats.

**Conclusions**: This study suggests that the beneficial effects of EE on motor symptoms after cerebellar damage may be, at least partly, because of modulation of neurotrophic proteins involved in the regeneration processes.

**Lui, C. C., Wang, J., Tain, Y., Chen, Y., Chang, K., Lai, M., & Huang, L. (2011). Prenatal stress in rat causes long-term spatial memory deficit and hippocampus MRI abnormality: Differential effects of postweaning enriched environment. *Neurochemistry International,58*(3), 434-441. doi:10.1016/j.neuint.2011.01.002**

Prenatal stress (PS) can cause long-term hippocampus alternations in structure and plasticity in adult offspring. Enriched environment (EE) has an effect in rescuing a variety of neurological disorders. Pregnant dams were left undisturbed (prenatal control, PC) or restrained 6 h per day from days 14 to 21 (prenatal stress, PS). Control and prenatal stressed offspring rats were subjected to a standard rearing environment (SE) or an EE on postnatal days 22–120 (PC/SE PC/EE, PS/SE, and PS/EE; *n* = 5, each group). At ∼4 months of age, all rats underwent Morris water maze test and brain MRI examination. Hippocampi were then dissected for biochemical analyses, including, Western blot for NMDA receptor (NR) subunits and synaptophysin and RT-PCR forβ1 integrin and tissue-plasminogen activator (t-PA). MRI showed all 5 rats in the PS/SE group and 5 in the PS/EE group exhibited increased signals in bilateral hippocampus and increased T2 time in the PS/SE group. Exposure to EE treatment on postnatal days 22–120 counteracted the deficit in spatial memory and increased NR1 protein expression, but it did not affect the rate of high signals and increased T2 time, decreased NR2, synaptophysin, β1 integrin and t-PA mRNA expressions in PS adult offspring. The results of this study indicate PS in rats causes long-term spatial memory deficits and gross hippocampus pathology. Postnatal EE treatment has differential benefits in terms of spatial learning, signaling molecules, and gross hippocampus pathology.

**2010**

**Morrongiello, B. A., Sandomierski, M., & Valla, J. (2010). Early identification of children at risk of unintentional injury: A sensation seeking scale for children 2–5 years of age. *Accident Analysis & Prevention,42*(4), 1332-1337. doi:10.1016/j.aap.2010.02.014**

Sensation seeking is a personality attribute associated with injury in school-age children, adolescents, and adults. This study aimed to develop and evaluate the psychometric properties of a questionnaire measure of sensation seeking for young children 2-5 years of age. Items tapping aspects of sensation seeking (Novelty Seeking, Behavioral Intensity, Thrill Seeking) were developed, content validation was completed by child development experts, and 72 parents then completed the Sensation Seeking Scale for Young Children (SSSYC) twice (3 months intervening) to establish internal and test-retest reliabilities. To assess criterion validity, scores were related to children's preferences for high versus low sensation seeking activities, their free play behavior in an indoor playroom, and to children's history of unintentional injuries. Indices of internal reliability and test-retest reliability were good and questionnaire scores positively correlated with sensation seeking behaviors during free play, preferences for high versus low sensation seeking activities, and injury measures, providing support for criterion validity. This initial evaluation of the SSSYC suggests that it is a psychometrically sound measure of sensation seeking. This scale may be useful for identifying high sensation seekers at young ages, providing the opportunity for early intervention to prevent unintentional injuries.

**Decker, S. L. (2010). Tactile measures in the structure of intelligence. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale, 64*(1), 53-59. doi:10.1037/a0015845**

This study investigated the relationship of tactile abilities within the framework of a hierarchical structure of mental abilities. Data were analysed from 229 participants who were administered tactile measures from the Dean-Woodcock Sensory Motor Battery along with a battery of conormed cognitive measures representative of the Cattell-Horn-Carroll (CHC) model of intelligence. Multiple measures of tactile performance were used including Palm Writing and Object Identification, and each measure included a lateralized measure (i.e., right/left). Factor analytic results suggest tactile measures have a significant relationship with measures of cognitive ability. In this study, tactile measures involving object identification were more related to cognitive measures of visual processing-speed and overall processing speed; whereas, tactile measures involving the recognition of numbers written on the palm of the hand produced high loadings on a separate factor. Results from this study suggest different tactile measures may differentially load on cognitive factors depending on the common processing demands of the tactile and cognitive measures. Suggestions for differentiating common processing demands between tactile and cognitive measures are discussed.

**Riquelme, I., & Montoya, P. (2010). Developmental changes in somatosensory processing in cerebral palsy and healthy individuals. *Clinical Neurophysiology,121*(8), 1314-1320. doi:10.1016/j.clinph.2010.03.010**

**Objectives:** Cerebral palsy (CP) is a motor disorder that causes physical disability in human development. Recent work has shown that somatosensory deficits are a serious problem for people with CP. There is however no information about the influence of age on brain correlates of tactile sensitivity.

**Methods:** Proprioception, touch and pain pressure thresholds, as well as somatosensory evoked potentials (SEP) elicited by tactile stimulation in lips and thumbs were examined in 15 children with CP (range 5–14 y), 14 adults with CP (range 22–55 y), 15 healthy children (range 5–14 y), and 15 healthy adults (range 22–42 y).

**Results:** Children with CP as compared to healthy controls showed more reduced sensitivity for non-painful stimuli, but enhanced sensitivity for painful stimuli. Early SEP amplitudes (P50 and P100) were more enhanced in children and adults with CP than in healthy participants. A functional hemispheric asymmetry was observed in CP when left- and right-side body parts were stimulated.

**Conclusions:** Data suggest the possibility that altered somatosensory brain processing in CP might be reflecting an enhanced excitability of the somatosensory cortex.

**Significance:** Assessment of somatosensory functions may have implications for future neuromodulatory treatment of pain complaints and motor rehabilitation programs in children and adults with cerebral palsy.

**Feldman, R., Singer, M., & Zagoory, O. (2010). Touch attenuates infants’ physiological reactivity to stress. *Developmental Science,13*(2), 271-278. doi:10.1111/j.1467-7687.2009.00890.x**

Animal studies demonstrate that maternal touch and contact regulate infant stress, and handling during periods of maternal deprivation attenuates the stress response. To measure the effects of touch on infant stress reactivity during simulated maternal deprivation, 53 dyads were tested in two paradigms: still-face (SF) and still-face with maternal touch (SF+T). Maternal and infant cortisol levels were sampled at baseline, reactivity, and recovery and mother's and infant's cardiac vagal tone were measured during the free play, still-face, and reunion episodes of the procedure. Cortisol reactivity was higher among infants in the SF condition and while cortisol decreased at recovery for infants in the SF+T, it further increased for those in the SF. Vagal tone showed a greater suppression when SF was not accompanied by maternal touch. Touch synchrony during free play was associated with higher infant vagal tone, whereas touch mys synchrony--maternal tactile stimulation while the infant gaze adverts--correlated with higher maternal and infant cortisol. In humans, as in mammals, the provision of touch during moments of maternal unavailability reduces infants' physiological reactivity to stress.

**James, K. H. (2010). Sensorimotor experience leads to changes in visual processing in the developing brain. *Developmental Science,13*(2), 279-288. doi:10.1111/j.1467-7687.2009.00883.x**

Since Broca's studies on language processing, cortical functional specialization has been considered to be integral to efficient neural processing. A fundamental question in cognitive neuroscience concerns the type of learning that is required for functional specialization to develop. To address this issue with respect to the development of neural specialization for letters, we used functional magnetic resonance imaging (fMRI) to compare brain activation patterns in pre-school children before and after different letter-learning conditions: a sensori-motor group practised printing letters during the learning phase, while the control group practised visual recognition. Results demonstrated an overall left-hemisphere bias for processing letters in these pre-literate participants, but, more interestingly, showed enhanced blood oxygen-level-dependent activation in the visual association cortex during letter perception only after sensorimotor (printing) learning. It is concluded that sensorimotor experience augments processing in the visual system of pre-school children. The change of activation in these neural circuits provides important evidence that 'learning-by-doing' can lay the foundation for, and potentially strengthen, the neural systems used for visual letter recognition.

**Cutuli, D., Rossi, S., Burello, L., Laricchiuta, D., Chiara, V. D., Foti, F., . . . Petrosini, L. (2011). Before or after does it matter? Different protocols of environmental enrichment differently influence motor, synaptic and structural deficits of cerebellar origin. *Neurobiology of Disease,42*(1), 9-20. doi:10.1016/j.nbd.2010.12.007**

Cerebellar compensation is a reliable model of lesion-induced plasticity occurring through profound synaptic and neurochemical modifications in cortical and sub-cortical regions. As the recovery from cerebellar deficits progresses, the firstly enhanced glutamate striatal transmission is then normalized. The time course of cerebellar compensation and the concomitant striatal modifications might be influenced by protocols of environmental enrichment (EE) differently timed in respect to cerebellar lesion. In the present study, we analyzed the effects of different EE protocols on postural and locomotor behaviors (by means of a neurological rating scale), and on striatal synaptic activity (by means of recordings of spontaneous glutamate-mediated excitatory postsynaptic currents (sEPSCs)) and on morphological correlates (by means of density and dendritic length of Fast Spiking (FS) interneurons) following hemi-cerebellectomy (HCb) in rats. Cerebellar motor deficits were reduced faster in the enriched animals in comparison to standard housed HCbed rats. The beneficial influence of EE was higher in the animals enriched before the HCb than in rats enriched only after the lesion. In parallel, the HCb-induced increase in striatal sEPSCs was not observed in rats enriched before HCb and attenuated in rats enriched after HCb. Furthermore, the EE prevented the shrinkage of dendritic arborization of FS striatal interneurons. Also this effect was more marked in animals enriched before than after the HCb. The exposure to EE exerted either neuro-protective or therapeutic actions on the cerebellar deficits. The experience-dependent changes of the synaptic and neuronal connectivity observed in the striatal neurons may represent one of the mechanisms through which the enrichment facilitates functional compensation following the cerebellar damage.

**Spilka, M. J., Steele, C. J., & Penhune, V. B. (2010). Gesture imitation in musicians and non-musicians. *Experimental Brain Research,204*(4), 549-558. doi:10.1007/s00221-010-2322-3**

Imitation plays a crucial role in the learning of many complex motor skills. Recent behavioral and neuroimaging evidence suggests that the ability to imitate is influenced by past experience, such as musical training. To investigate the impact of musical training on motor imitation, musicians and non-musicians were tested on their ability to imitate videoclips of simple and complex two-handed gestures taken from American Sign Language. Participants viewed a set of 30 gestures, one at a time, and imitated them immediately after presentation. Participants' imitations were videotaped and scored off-line by raters blind to participant group. Imitation performance was assessed by a rating of performance accuracy, where the arm, hand, and finger components of the gestures were rated separately on a 5-point scale (1 = unrecognizable; 5 = exact imitation). A global accuracy score (PAglobal) was calculated by summing the three components. Response duration compared to the model (%MTdiff), and reaction time (RT) were also assessed. Results indicated that musicians were able to imitate more accurately than non-musicians, reflected by significantly higher PAglobal and lower %MTdiff scores. Furthermore, the greatest difference in performance was for the fine-motor (finger) gesture component. These findings support the view that the ability to imitate is influenced by experience. This is consistent with generalist theories of motor imitation, which explain imitation in terms of links between perceptual and motor action representations that become strengthened through experience. It is also likely that musical training contributed to the ability to imitate manual gestures by influencing the personal action repertoire of musicians.

**Gelfo, F., Cutuli, D., Foti, F., Laricchiuta, D., Bartolo, P. D., Caltagirone, C., . . . Angelucci, F. (2010). Enriched Environment Improves Motor Function and Increases Neurotrophins in Hemicerebellar Lesioned Rats. *Neurorehabilitation and Neural Repair,25*(3), 243-252. doi:10.1177/1545968310380926**

**Background:** Environmental enrichment (EE) defined as “a combination of complex inanimate and social stimulation” influences brain function and anatomy by enhancing sensory, cognitive, motor, and social stimulation. The beneficial effects of EE in the presence of brain damage have been partially attributed to upregulation of neurotrophins, proteins involved in neuronal survival and in activity-dependent plasticity.

**Objective:** The authors tested the hypothesis that EE may have advantageous effects on recovery of motor function after cerebellar damage, associated with changes in local neurotrophin production. **Methods:** They performed a hemi cerebellectomy in rats previously exposed to EE or reared in standard conditions. The time course of compensation of motor symptoms was analyzed in both lesioned groups. Then, the local production of the nerve growth factor (NGF) and brain-derived neurotrophic factor (BDNF) in the spared hemi cerebellum and other extra cerebellar regions was evaluated.

**Results***:* Long-term exposure to EE accelerated the motor recovery in hemicerebellectomized rats and elicited an increase in NGF levels in the spared hemi cerebellum, as compared with non-enriched lesioned and control rats. BDNF levels were higher in hemicerebellectomized rats but not influenced by EE. In the frontal cortex, both NGF and BDNF levels were upregulated in hemicerebellectomized enriched rats as compared with hemicerebellectomized non-enriched and control rats.

**Conclusions***:* This study suggests that the beneficial effects of EE on motor symptoms after cerebellar damage may be, at least partly, because of modulation of neurotrophic proteins involved in the regeneration processes.

**2009**

**Bruno, R. M., Hahn, T. T., Wallace, D. J., Kock, C. P., & Sakmann, B. (2009). Sensory Experience Alters Specific Branches of Individual Corticocortical Axons during Development. *Journal of Neuroscience, 29*(10), 3172-3181. doi:10.1523/jneurosci.5911-08.2009**

Sensory experience can, over the course of days to weeks, produce long-lasting changes in brain function. Recent studies suggest that functional plasticity is mediated by alterations of the strengths of existing synapses or dynamics of dendritic spines. Alterations of cortical axons could also contribute to functional changes, but little is known about the effects of experience at the level of individual corticocortical axons. We reconstructed individual layer (L) 2/3 pyramidal neurons filled in vivo in developing barrel cortex of control and partially sensory-deprived rats. L2 axons had larger field spans than L3 axons but were otherwise equivalently affected by deprivation. Whisker trimming over approximately 2 weeks markedly reduced overall length of axonal branches in L2/3, but individual horizontal axons were as likely to innervate deprived areas as spared ones. The largest effect of deprivation was instead to reduce the length of those axonal branches in L2/3 oriented toward deprived regions. Thus, the location of a branch relative to its originating soma, rather than its own location within any specific cortical column, was the strongest determinant of axonal organization. Individual axons from L2/3 into L5/6 were similarly altered by whisker trimming although to a lesser extent. Thus, sensory experience over relatively short timescales may change the patterning of specific axonal branches within as well as between cortical columns during development.

**Scholey, A., Haskell, C., Robertson, B., Kennedy, D., Milne, A., & Wetherell, M. (2009). Chewing gum alleviates negative mood and reduces cortisol during acute laboratory psychological stress. *Physiology & Behavior,97*(3-4), 304-312. doi:10.1016/j.physbeh.2009.02.028**

The notion that chewing gum may relieve stress was investigated in a controlled setting. A multi-tasking framework which reliably evokes stress and also includes performance measures was used to induce acute stress in the laboratory. Using a randomised crossover design forty participants (mean age 21.98 years) performed on the multi-tasking framework at two intensities (on separate days) both while chewing and not chewing. Order of workload intensity and chewing conditions were counterbalanced. Before and after undergoing the platform participants completed the state portion of the State-Trait Anxiety Inventory, Bond–Lader visual analogue mood scales, a single Stress Visual Analogue Scale and provided saliva samples for cortisol measurement. Baseline measures showed that both levels of the multi-tasking framework were effective in significantly reducing self-rated alertness, calmness and contentment while increasing self-rated stress and state anxiety. Cortisol levels fell during both levels of the stressor during the morning, reflecting the predominance of a.m. diurnal changes, but this effect was reversed in the afternoon which may reflect a measurable stress response. Pre–post stressor changes (Δ) for each measure at baseline were subtracted from Δ scores under chewing and no chewing conditions. During both levels of stress the chewing gum condition was associated with significantly better alertness and reduced state anxiety, stress and salivary cortisol. Overall performance on the framework was also significantly better in the chewing condition. The mechanisms underlying these effects are unknown but may involve improved cerebral blood flow and/or effects secondary to performance improvement during gum chewing.

**Ali, A. E., Wilson, Y. M., & Murphy, M. (2009). A single exposure to an enriched environment stimulates the activation of discrete neuronal populations in the brain of the fos-tau-lacZ mouse. *Neurobiology of Learning and Memory,92*(3), 381-390. doi:10.1016/j.nlm.2009.05.004**

Storage of experience, including learning and memory, is thought to involve plasticity within pre-existing brain circuits. One model for looking at experience-dependent changes is environmental enrichment (EE), which involves exposing animals to a complex novel environment. Animals exposed to EE have previously been shown to exhibit a variety of behavioral and structural alterations in the brain, including decreased stress, improved learning and memory, altered levels of immediate early genes and synaptic change in the visual cortex. We were interested in understanding what regions of the brain are activated during the initial stages of EE. We used fos-tau-lacZ (FTL) transgenic mice to examine changes in functional activation throughout the brain after a single exposure to EE. We found that there was a significant increase in FTL expression within particular morphologically identified neurons in a series of brain regions in the enriched group compared to control groups, indicating that multiple circuits were activated. These regions include the claustrum, infralimbic cortex, hippocampus, amygdala and the hypothalamus. The data suggest that EE stimulates an initial strong increase in activation of multiple functional circuits. These circuits are presumably involved in the initial response of the animal to the enriched environment.

**Pawlowicz, A., Demner, A., & Lewis, M. H. (2010). Effects of access to voluntary wheel running on the development of stereotypy. *Behavioural Processes,83*(3), 242-246. doi:10.1016/j.beproc.2009.11.008**

Stereotyped motor behaviors are a common consequence of

environmental restriction in a wide variety of species. Although environmental enrichment has been shown to substantially reduce stereotypy levels, the various components of enrichment have not been evaluated independently to determine which is responsible for this effect. Exercise, particularly voluntary wheel running, is a promising candidate based on several lines of behavioral and neurobiological evidence. To test the hypothesis that access to wheel running will reduce stereotyped motor behavior, we reared deer mice from weaning with continuous access to either a functional running wheel or a locked wheel. We assessed running behavior throughout this time period and stereotypy levels in a test context at 30 and 45 days post-weaning. We found that exercise did not significantly affect stereotypy level nor was there an association between wheel running and stereotypy. Thus, exercise alone, unlike environmental enrichment, does not prevent the development of stereotypy. These results have important implications for animal welfare.

**Catlow, B. J., Rowe, A. R., Clearwater, C. R., Mamcarz, M., Arendash, G. W., & Sanchez-Ramos, J. (2009). Effects of environmental enrichment and physical activity on neurogenesis in transgenic PS1/APP mice. *Brain Research,1256*, 173-179. doi:10.1016/j.brainres.2008.12.028**

Rodents exposed to environmental enrichment show many differences, including improved cognitive performance, when compared to those living in standard (impoverished) housing. The purpose of the present study was to determine if a selective increase in neurogenesis occurred in cognitively-protected Tg mice raised in an enriched environment compared to those reared in physical activity housing. At weaning, double Tg APP+PS1 mice were placed into one of three environments: complete environmental enrichment (CE), enhanced physical activity (PA), or individual, impoverished housing (IMP). At 9–10 months of age, Tg mice were injected with BrdU (100 mg/kg BID) followed by euthanasia either 24 h or 2 weeks after the last injection. Unbiased estimates of BrdU positive cells in the hippocampal subgranular zone revealed a significant increase in cellular proliferation in Tg mice raised in CE or PA compared to Tg mice reared in IMP housing. However, counts of BrdU birth-dated cells 2 weeks after labeling showed no difference among the three groups, indicating decreased survival of cells in those groups (CE and PA) with higher cellular proliferation rates in the neurogenic niche. Counts of calretinin-expressing cells, a marker of immature neurons, also indicated no difference among the three groups of mice. In view of our prior study showing that enhanced cognitive activity (but not enhanced physical activity) protects Tg mice against cognitive impairment, the present results indicate that increased generation and survival of new neurons in the hippocampal dentate gyrus is not involved with the cognitively-protective effects of complete CE in Alzheimer's transgenic mice. (PsycINFO Database Record (c) 2009 APA, all rights reserved)

**Hughes, R. N., & Collins, M. A. (2010). Enhanced habituation and decreased anxiety by environmental enrichment and possible attenuation of these effects by chronic α-tocopherol (vitamin E) in aging male and female rats. *Pharmacology Biochemistry and Behavior,94*(4), 534-542. doi:10.1016/j.pbb.2009.11.008**

Middle-aged 330-day-old male and female hooded rats were group-housed for nearly 5 months in either standard cages, or in cages containing objects. Each cage also provided either pure water, or a solution of vitamin E (DL-α-tocopherol acetate) for drinking. Records were kept of averages for each cage of the rats' body weights and the volume of fluid/100g average body weight drunk. The average daily dose of tocopherol was approximately 162 and 173mg/kg for males and females respectively. Males (but not females) kept in enriched cages weighed less than those from standard cages. They also drank less fluid than females who also drank more tocopherol solution than males. When 490+days old, for rats provided with water, enrichment led to decreased open-field ambulation and increased within-session decrements in the response (habituation). Enrichment also led to decreased occupancy of the center of the apparatus for males only and, for all rats combined, increased grooming behavior. It was concluded that the effects of enrichment on aged rats were due to increased within-session habituation to novelty and decreased anxiety similar to what has been suggested for younger animals. Tocopherol appeared to interfere with effects of enrichment possibly because of pro-oxidant-related increased anxiety.

**Sale, A., Berardi, N., & Maffei, L. (2009). Enrich the environment to empower the brain. *Trends in Neurosciences,32*(4), 233-239. doi:10.1016/j.tins.2008.12.004**

Environmental enrichment (EE) has long been exploited to investigate the influence of the environment on brain structure and function. Robust morphological and functional effects elicited by EE at the neuronal level have been reported to be accompanied by improvements in cognitive performance. Recently, EE has been shown to accelerate the development of the visual system and to enhance visual-cortex plasticity in adulthood. These new findings highlight the potential of EE as a promising noninvasive strategy to ameliorate deficits in the maturation of the nervous system and to promote recovery of normal sensory functions in pathological conditions affecting the adult brain.

**Nag, N., Moriuchi, J. M., Peitzman, C. G., Ward, B. C., Kolodny, N. H., & Berger-Sweeney, J. E. (2009). Environmental enrichment alters locomotor behaviour and ventricular volume in Mecp21lox mice. *Behavioural Brain Research,196*(1), 44-48. doi:10.1016/j.bbr.2008.07.008**

Rett syndrome (RTT) is an autistic spectrum developmental disorder associated with mutations in the X-linked Mecp2 gene, and severe behavioural and neuropathological deficits. In a mouse model of RTT (Mecp2[sup] <xh:i>1lox[/sup]1lox), we examined whether environmental enrichment (EE) alters behavioural performance and regional brain volume. At weaning, Mecp2[sup] <xh:i>1lox[/sup]1lox and control mice were assigned to enriched or standard housing. From postnatal day 29 to 43, mice were subjected to behavioural tasks measuring motor and cognitive performance. At postnatal day 44, volumes of whole brain, cerebellum, ventricles, and motor cortex were measured using magnetic resonance imaging. EE provided subtle improvements to locomotor activity and contextual fear conditioning in Mecp2[sup] <xh:i>1lox[/sup]1lox mice. Additionally, EE reduced ventricular volumes, which correlated with improved locomotor activity, suggesting that neuroanatomical changes contribute to improved behaviour. Our results suggest that post-weaning EE may provide a non-invasive palliative treatment for RTT.

**Carvalho, C. R., Pandolfo, P., Pamplona, F. A., & Takahashi, R. N. (2010). Environmental enrichment reduces the impact of novelty and motivational properties of ethanol in spontaneously hypertensive rats. *Behavioural Brain Research,208*(1), 231-236. doi:10.1016/j.bbr.2009.11.043**

The present study investigated the consequences of environmental enrichment on the impact of novelty and motivational properties of ethanol in spontaneously hypertensive rats (SHR), a validated model of attention deficit hyperactivity disorder (ADHD). This rat strain displays increased sensitivity to distinct classes of abused drugs, which makes it an interesting model for the study of the association between ADHD and drug abuse. Female SHR reared from weaning to adulthood in standard (SE) or enriched (EE) environment were tested on novelty-induced locomotion, saccharin consumption, ethanol consumption (forced and free-choice schedules) and ethanol-induced conditioned place preference (CPP). SHR reared in an EE showed reduced novelty-induced locomotion, consumed less saccharin and ethanol in a forced schedule and showed less ethanol preference in a free-choice schedule compared to SE rats. Moreover, EE rats did not develop CPP, whereas SE rats developed preference for ethanol (1.2g/kg). These results show that exposure to stimuli mimicking positive life experiences (environmental enrichment) induces persistent changes in the reward/motivational system of female SHR, suggesting an important role of the familiar environment during early stages of the neurodevelopment on the co-morbidity of ADHD and drug abuse. (PsycINFO Database Record (c) 2009 APA, all rights reserved)

**Harrar, V., & Harris, L. R. (2009). Eye position affects the perceived location of touch. *Experimental Brain Research,198*(2-3), 403-410. doi:10.1007/s00221-009-1884-4**

Here, we demonstrate a systematic shift in the perceived location of a tactile stimulus on the arm toward where the eye is looking. Participants reported the perceived position of touches presented between the elbow and the wrist while maintaining eye positions at various eccentricities. The perceived location of the touch was shifted by between 1 and 5 cm (1.9°–9.5° visual angle) by a change in eye position of ±25° from straight ahead. In a control condition, we repeat the protocol with the eyes fixating straight ahead. Changes in attention accounted for only 17% of the shift due to eye position. The pattern of tactile shifts due to eye position was comparable whether or not the arm was visible. However, touches at locations along the forearm were perceived as being farther apart when the arm was visible compared to when it was covered. These results are discussed in terms of the coding of tactile space, which seems to require integration of tactile, visual and eye position information.

**Tall, J. (2009). Housing supplementation decreases the magnitude of inflammation-induced nociception in rats. *Behavioural Brain Research,197*(1), 230-233. doi:10.1016/j.bbr.2008.08.010**

Previous reports have demonstrated that pain is influenced by environmental factors. This investigation examined the effects of housing supplementation, via the inclusion of objects to the home cage environment, on inflammation-induced nociceptive behaviors. The degree of thermal hyperalgesia was significantly lower in rats housed in a supplemented home cage environment, as compared to rats housed in basic cages. These data indicate that environmental enrichment significantly affects nociceptive responses.

**Lewis, C. M., Baldassarre, A., Committeri, G., Romani, G. L., & Corbetta, M. (2009). Learning sculpts the spontaneous activity of the resting human brain. *Proceedings of the National Academy of Sciences,106*(41), 17558-17563. doi:10.1073/pnas.0902455106**

The brain is not a passive sensory-motor analyzer driven by environmental stimuli, but actively maintains ongoing representations that may be involved in the coding of expected sensory stimuli, prospective motor responses, and prior experience. Spontaneous cortical activity has been proposed to play an important part in maintaining these ongoing, internal representations, although its functional role is not well understood. One spontaneous signal being intensely investigated in the human brain is the interregional temporal correlation of the blood-oxygen level-dependent (BOLD) signal recorded at rest by functional MRI (functional connectivity-by-MRI, fcMRI, or BOLD connectivity). This signal is intrinsic and coherent within a number of distributed networks whose topography closely resembles that of functional networks recruited during tasks. While it is apparent that fcMRI networks reflect anatomical connectivity, it is less clear whether they have any dynamic functional importance. Here, we demonstrate that visual perceptual learning, an example of adult neural plasticity, modifies the resting covariance structure of spontaneous activity between networks engaged by the task. Specifically, after intense training on a shape-identification task constrained to one visual quadrant, resting BOLD functional connectivity and directed mutual interaction between trained visual cortex and frontal-parietal areas involved in the control of spatial attention were significantly modified. Critically, these changes correlated with the degree of perceptual learning. We conclude that functional connectivity serves a dynamic role in brain function, supporting the consolidation of previous experience.

**Viel, S., Vaugoyeau, M., & Assaiante, C. (2009). Adolescence: A Transient Period of Proprioceptive Neglect in Sensory Integration of Postural Control. *Motor Control,13*(1), 25-42. doi:10.1123/mcj.13.1.25**

In the current study, we adopted the hypothesis that the body scheme disturbances occurring during adolescence might lead subjects to transiently neglect proprioceptive information and that adolescents might rely more strongly on vision to control their orientation and stabilize their body. To check this point, we asked adolescents 14-15 years to maintain vertical stance while very slow sinusoidal oscillations in the frontal plane were applied to the supporting platform at 0.01 Hz (below the detection threshold of the semicircular canal system) and at 0.06 Hz (above) with the eyes open and closed. Two postural components, orientation and segmental stabilization, were analyzed at the head, shoulder, trunk, and pelvis levels. At the lowest frequency without vision, the performances of adolescents were much less efficient than those of adults. Moreover, this study showed that vision plays a predominant role in adolescents' control of orientation and body stabilization. At 0.06 Hz without vision, a clearcut difference was observed between the strategies used by girls and boys; specifically, the maturation of the segmental stabilization processes was found to be more advanced in girls than in boys. However, no such difference was observed at 0.01 Hz. Lastly, comparisons between the data obtained in adolescents and those previously obtained in young adults (Vaugoyeau, Viel, Amblard, Azulay, & Assaiante, 2008) clearly show that adolescents use different postural strategies and that they are not yet capable of reaching comparable postural performance levels to those observed in adults. Because adolescents were not able to use the proprioceptive information available to improve their postural control, we concluded that they showed a maturational lag in comparison with adults. This suggests that the mechanisms underlying postural control are still maturing during adolescence, which might constitute a transient period of proprioceptive neglect in sensory integration of postural control.

**Gottfried, J. A., & Wu, K. N. (2009). Perceptual and Neural Pliability of Odor Objects. *Annals of the New York Academy of Sciences,1170*(1), 324-332. doi:10.1111/j.1749-6632.2009.03917.x**

A key function of the sense of smell is to guide organisms towards rewards and away from dangers. However, because relatively few volatile chemicals in the environment carry intrinsic biological value, the meaning of an odor often needs to be acquired through learning and experience. The tremendous perceptual and neural plasticity of the olfactory system provides a design that is ideal for the establishment of links between odor cues and behaviorally relevant events, promoting appropriate adaptive responses to foods, friends, foes, and mates. This article describes recent human neuroimaging data showing the dynamic effects of olfactory perceptual learning and aversive conditioning on the behavioral discrimination of odor objects, with parallel plasticity and reorganization in the posterior piriform and orbitofrontal cortices. The findings presented here highlight the important role of experience in shaping odor object perception and in ensuring the human sense of smell achieves its full perceptual potential.

**Nithianantharajah, J., & Hannan, A. J. (2009). The neurobiology of brain and cognitive reserve: Mental and physical activity as modulators of brain disorders. *Progress in Neurobiology,89*(4), 369-382. doi:10.1016/j.pneurobio.2009.10.001**

The concept of 'cognitive reserve', and a broader theory of 'brain reserve', were originally proposed to help explain epidemiological data indicating that individuals who engaged in higher levels of mental and physical activity via education, occupation and recreation, were at lower risk of developing Alzheimer's disease and other forms of dementia. Subsequently, behavioral, cellular and molecular studies in animals (predominantly mice and rats) have revealed dramatic effects of environmental enrichment, which involves enhanced levels of sensory, cognitive and motor stimulation via housing in novel, complex environments. Furthermore, increasing levels of voluntary physical exercise, via ad libitum access to running wheels, can have significant effects on brain and behavior, thus informing the relative effects of mental and physical activity. More recently, animal models of brain disorders have been compared under environmentally stimulating and standard housing conditions, and this has provided new insights into environmental modulators and gene-environment interactions involved in pathogenesis. Here, we review animal studies that have investigated the effects of modifying mental and physical activity via experimental manipulations, and discuss their relevance to brain and cognitive reserve (BCR). Recent evidence suggests that the concept of BCR is not only relevant to brain aging, neurodegenerative diseases and dementia, but also to other neurological and psychiatric disorders. Understanding the cellular and molecular mechanisms mediating BCR may not only facilitate future strategies aimed at optimising healthy brain aging, but could also identify molecular targets for novel pharmacological approaches aimed at boosting BCR in 'at risk' and symptomatic individuals with various brain disorders.

**Catlow, B. J., Rowe, A. R., Clearwater, C. R., Mamcarz, M., Arendash, G. W., & Sanchez-Ramos, J. (2009). Effects of environmental enrichment and physical activity on neurogenesis in transgenic PS1/APP mice. *Brain Research,1256*, 173-179. doi:10.1016/j.brainres.2008.12.028**

Rodents exposed to environmental enrichment show many differences, including improved cognitive performance, when compared to those living in standard (impoverished) housing. The purpose of the present study was to determine if a selective increase in neurogenesis occurred in cognitively-protected Tg mice raised in an enriched environment compared to those reared in physical activity housing. At weaning, double Tg APP+PS1 mice were placed into one of three environments: complete environmental enrichment (CE), enhanced physical activity (PA), or individual, impoverished housing (IMP). At 9-10 months of age, Tg mice were injected with BrdU (100 mg/kg BID) followed by euthanasia either 24 h or 2 weeks after the last injection. Unbiased estimates of BrdU positive cells in the hippocampal subgranular zone revealed a significant increase in cellular proliferation in Tg mice raised in CE or PA compared to Tg mice reared in IMP housing. However, counts of BrdU birth-dated cells 2 weeks after labeling showed no difference among the three groups, indicating decreased survival of cells in those groups (CE and PA) with higher cellular proliferation rates in the neurogenic niche. Counts of calretinin-expressing cells, a marker of immature neurons, also indicated no difference among the three groups of mice. In view of our prior study showing that enhanced cognitive activity (but not enhanced physical activity) protects Tg mice against cognitive impairment, the present results indicate that increased generation and survival of new neurons in the hippocampal dentate gyrus is not involved with the cognitively-protective effects of complete CE in Alzheimer's transgenic mice.

**Trickett, S. L., Guy, J. H., & Edwards, S. A. (2009). The role of novelty in environmental enrichment for the weaned pig. *Applied Animal Behaviour Science,116*(1), 45-51. doi:10.1016/j.applanim.2008.07.007**

**Abstract**: Habituation to environmental enrichment objects can occur rapidly. Novelty of an object is an important property involved in initiating and maintaining exploration, and this can be achieved by renewing objects. The aims of this study were to assess whether alternation of two contrasting objects increased enrichment value, and whether simultaneous access increased overall object-directed behaviour in comparison with single presentation of each object. The experiment was designed as a 2 × 2 factorial, with 2 enrichment objects (suspended rope and loose wood block) and 2 presentation methods (continuous access, or weekly alternation). An additional treatment examined object use when both objects were presented simultaneously. Five replicate pens, each of 10 weaned pigs, were allocated to each treatment: R, continuous rope; W, continuous wood; R/W, alternation rope-wood; W/R, alternation wood-rope; R + W, simultaneous rope and wood. Observations of behaviour were made for two 1-h periods, three times a week for a 4-week period. Direct scan samples at 5-min intervals measured use of the enrichment object(s), penmate and pen manipulation, and general activity. These were supplemented by two 24 h time-lapse video recordings made in the first and last experimental weeks. Object interaction was significantly affected by treatment, with W spending a lower overall proportion of observations in contact with the object than the other treatments (in order 0.102, 0.037, 0.093, 0.110, 0.134, s.e.d. 0.007; P < 0.001). In R, week had a significant effect on rope interaction, which decreased in week 2 and increased again in week 3 when new rope was added, although rope interaction was still lower in week 3 than in week 1 (0.106 vs. 0.151, respectively, s.e.d. 0.017; P < 0.01). When R/W and W/R received rope for a second time, rope interaction was lower than in the first presentation week (R/W, 0.166 vs. 0.129, s.e.d. 0.017; P < 0.05). Interaction with wood was always lower than with rope (in R + W, 0.03 vs. 0.19, respectively, s.e.d. 0.027; P < 0.001). Object interaction was additive in R + W when compared to R and W. To conclude, the rotation of enrichment objects did increase novelty, although habituation still occurred. Rope was extremely effective at occupying the pigs’ time, with interaction levels comparable to those previously reported for straw.

**Simonetti, T., Lee, H., Bourke, M., Leamey, C. A., & Sawatari, A. (2009). Enrichment from birth accelerates the functional and cellular development of a motor control area in the mouse. *PLoS ONE,4*(8). doi:10.1371/journal.pone.0006780**

**Background**: There is strong evidence that sensory experience in early life has a profound influence on the development of sensory circuits. Very little is known, however, about the role of experience in the early development of striatal networks which regulate both motor and cognitive function. To address this, we have investigated the influence of early environmental enrichment on motor development.

**Methods:** Mice were raised in standard or enriched housing from birth. For animals assessed as adults, half of the mice had their rearing condition reversed at weaning to enable the examination of the effects of pre- versus post-weaning enrichment. We found that exclusively pre-weaning enrichment significantly improved performance on the Morris water maze compared to non-enriched mice. The effects of early enrichment on the emergence of motor programs were assessed by performing behavioural tests at postnatal day 10. Enriched mice traversed a significantly larger region of the test arena in an open-field test and had improved swimming ability compared to non-enriched cohorts. A potential cellular correlate of these changes was investigated using Wisteria-floribunda agglutinin (WFA) staining to mark chondroitin-sulfate proteoglycans (CSPGs). We found that the previously reported transition of CSPG staining from striosome-associated clouds to matrix-associated perineuronal nets (PNNs) is accelerated in enriched mice. **Conclusions/Significance:** This is the first demonstration that the early emergence of exploratory as well as coordinated movement is sensitive to experience. These behavioural changes are correlated with an acceleration of the emergence of striatal PNNs suggesting that they may consolidate the neural circuits underlying these behaviours. Finally, we confirm that pre-weaning experience can lead to life long changes in the learning ability of mice.

**Zajac, M., Pang, T., Wong, N., Weinrich, B., Leang, L., Craig, J., . . . Hannan, A. (2009). Wheel running and environmental enrichment differentially modify exon-specific BDNF expression in the hippocampus of wild-type and pre-motor symptomatic male and female Huntington’s disease mice. *Hippocampus*. doi:10.1002/hipo.20658**

Brain-derived neurotrophic factor (BDNF) is an essential neurotrophin and regulation of its expression is complex due to multiple 5' untranslated exons which are separately spliced to a common coding exon to form unique mRNA transcripts. Disruption of BDNF gene expression is a key to the development of symptoms in Huntington's disease (HD), a fatal neurodegenerative condition. Abnormal epigenetic modifications are associated with reduced gene expression in late-stage HD but such regulation of BDNF gene expression has yet to be investigated. We hypothesized that BDNF gene expression is altered in the HD hippocampus of pre-motor symptomatic R6/1 transgenic HD mice, correlating with a change in the DNA methylation profile. The effects of wheel-running and environmental enrichment on wild-type mice, in association with a proposed environment-mediated correction of BDNF gene expression deficits in HD mice, were also investigated. Using real-time PCR, levels of total BDNF mRNA were found to be reduced in the hippocampus of both male and female HD mice. Wheel-running significantly increased total BDNF gene expression in all groups of mice except male HD mice. In contrast, environmental enrichment significantly increased expression only in male wild-type animals. Further quantification of BDNF exon-specific transcripts revealed sex-specific changes in relation to the effect of the HD mutation and differential effects on gene expression by wheel-running and environmental enrichment. The HD-associated reduction of BDNF gene expression was not due to increased methylation of the gene sequence. Furthermore, environment-induced changes in BDNF gene expression in the wild-type hippocampus were independent of the extent of DNA methylation. Overall, the results of this study provide new insight into the role of BDNF in HD pathogenesis in addition to the mechanisms regulating normal BDNF gene expression. (c) 2009 Wiley-Liss, Inc.

**Peña, Y., Prunell, M., Rotllant, D., Armario, A., & Escorihuela, R. M. (2009). Enduring effects of environmental enrichment from weaning to adulthood on pituitary-adrenal function, pre-pulse inhibition and learning in male and female rats. *Psychoneuroendocrinology,34*(9), 1390-1404. doi:10.1016/j.psyneuen.2009.04.019**

Environmental enrichment (EE) increases stimulation and provides richer sensory, cognitive and motor opportunities through the interaction with the social and physical environment. EE produces a wide range of neuroanatomical, neurochemical and behavioural effects in several animal species. However, the effects of EE have mainly been studied shortly after the treatment, so its long-lasting effects remain to be elucidated. Thus, we studied in male and female Sprague-Dawley rats the enduring effects of EE on tasks that measured emotional reactivity, social exploration and memory, sensorimotor gating and learning. After weaning, rats reared in EE were housed in single-sex groups of 12-14 in enriched cages during 12 weeks, whereas control rats were housed in single-sex groups of 2-3 animals in standard cages. Then, all rats were housed in pairs and successively exposed to different tests between 4 and 60 weeks post-EE. The results indicated that animals of both sexes reared in EE gained less weight during the enrichment period; differences disappeared in females during the post-EE period, but were maintained intact in males. Rats reared in EE showed an altered daily pattern of corticosterone and a lower hormone response to a novel environment (hole board, HB), although no differences in ACTH were found. EE resulted in more exploratory behaviour in the HB and higher number of entries in the open arms of the elevated plus maze (with no changes in the time spent in the open arms), suggesting a greater motivation to explore. Unexpectedly, rats reared in EE showed reduced pre-pulse inhibition (PPI), a measure of sensorimotor gating, suggesting lower capability to filter non-relevant information compared with control rats. EE increased social exploratory behaviour towards juvenile rats and social discrimination in males, but decreased social discrimination in females. Finally, in the Hebb-Williams maze, rats reared in EE showed better performance in terms of reduced number of errors and shorter distances travelled in the mazes. It is concluded that EE exposure from weaning to adulthood has important and long-lasting consequences on physiological and behavioural variables, most of them similar in both sexes, although sex differences in response to the EE are also reported.

**Megevand, P., Troncoso, E., Quairiaux, C., Muller, D., Michel, C. M., & Kiss, J. Z. (2009). Long-Term Plasticity in Mouse Sensorimotor Circuits after Rhythmic Whisker Stimulation. *Journal of Neuroscience,29*(16), 5326-5335. doi:10.1523/jneurosci.5965-08.2009**

Mice actively explore their environment by rhythmically sweeping their whiskers. As a consequence, neuronal activity in somatosensory pathways is modulated by the frequency of whisker movement. The potential role of rhythmic neuronal activity for the integration and consolidation of sensory signals, however, remains unexplored. Here, we show that a brief period of rhythmic whisker stimulation in anesthetized mice resulted in a frequency-specific long-lasting increase in the amplitude of somatosensory-evoked potentials in the contralateral primary somatosensory (barrel) cortex. Mapping of evoked potentials and intracortical recordings revealed that, in addition to potentiation in layers IV and II/III of the barrel cortex, rhythmic whisker stimulation induced a decrease of somatosensory-evoked responses in the supragranular layers of the motor cortex. To assess whether rhythmic sensory input-based plasticity might arise in natural settings, we exposed mice to environmental enrichment. We found that it resulted in somatosensory-evoked responses of increased amplitude, highlighting the influence of previous sensory experience in shaping sensory responses. Importantly, environmental enrichment-induced plasticity occluded further potentiation by rhythmic stimulation, indicating that both phenomena share common mechanisms. Overall, our results suggest that natural, rhythmic patterns of whisker activity can modify the cerebral processing of sensory information, providing a possible mechanism for learning during sensory perception.

**Pawlowicz, A., Demner, A., & Lewis, M. H. (2010). Effects of access to voluntary wheel running on the development of stereotypy. *Behavioural Processes,83*(3), 242-246. doi:10.1016/j.beproc.2009.11.008**

Stereotyped motor behaviors are a common consequence of environmental restriction in a wide variety of species. Although environmental enrichment has been shown to substantially reduce stereotypy levels, the various components of enrichment have not been evaluated independently to determine which is responsible for this effect. Exercise, particularly voluntary wheel running, is a promising candidate based on several lines of behavioral and neurobiological evidence. To test the hypothesis that access to wheel running will reduce stereotyped motor behavior, we reared deer mice from weaning with continuous access to either a functional running wheel or a locked wheel. We assessed running behavior throughout this time period and stereotypy levels in a test context at 30 and 45 days post-weaning. We found that exercise did not significantly affect stereotypy level nor was there an association between wheel running and stereotypy. Thus, exercise alone, unlike environmental enrichment, does not prevent the development of stereotypy. These results have important implications for animal welfare.

**Hyde, K. L., Lerch, J., Norton, A., Forgeard, M., Winner, E., Evans, A. C., & Schlaug, G. (2009). Musical Training Shapes Structural Brain Development. *Journal of Neuroscience,29*(10), 3019-3025. doi:10.1523/jneurosci.5118-08.2009**

The human brain has the remarkable capacity to alter in response to environmental demands. Training-induced structural brain changes have been demonstrated in the healthy adult human brain. However, no study has yet directly related structural brain changes to behavioral changes in the developing brain, addressing the question of whether structural brain differences seen in adults (comparing experts with matched controls) are a product of "nature" (via biological brain predispositions) or "nurture" (via early training). Long-term instrumental music training is an intense, multisensory, and motor experience and offers an ideal opportunity to study structural brain plasticity in the developing brain in correlation with behavioral changes induced by training. Here we demonstrate structural brain changes after only 15 months of musical training in early childhood, which were correlated with improvements in musically relevant motor and auditory skills. These findings shed light on brain plasticity and suggest that structural brain differences in adult experts (whether musicians or experts in other areas) are likely due to training-induced brain plasticity.

**Guzzetta, A., Baldini, S., Bancale, A., Baroncelli, L., Ciucci, F., Ghirri, P., . . . Maffei, L. (2009). Massage Accelerates Brain Development and the Maturation of Visual Function. *Journal of Neuroscience,29*(18), 6042-6051. doi:10.1523/jneurosci.5548-08.2009**

Environmental enrichment (EE) was shown recently to accelerate brain development in rodents. Increased levels of maternal care, and particularly tactile stimulation through licking and grooming, may represent a key component in the early phases of EE. We hypothesized that enriching the environment in terms of body massage may thus accelerate brain development in infants. We explored the effects of body massage in preterm infants and found that massage accelerates the maturation of electroencephalographic activity and of visual function, in particular visual acuity. In massaged infants, we found higher levels of blood IGF-1. Massage accelerated the maturation of visual function also in rat pups and increased the level of IGF-1 in the cortex. Antagonizing IGF-1 action by means of systemic injections of the IGF-1 antagonist JB1 blocked the effects of massage in rat pups. These results demonstrate that massage has an influence on brain development and in particular on visual development and suggest that its effects are mediated by specific endogenous factors such as IGF-1.

**Zhu, S., Codita, A., Bogdanovic, N., Hjerling-Leffler, J., Ernfors, P., Winblad, B., . . . Mohammed, A. H. (2009). Influence of environmental manipulation on exploratory behaviour in male BDNF knockout mice. *Behavioural Brain Research,197*(2), 339-346. doi:10.1016/j.bbr.2008.09.032**

It is widely accepted that brain derived neurotrophic factor (BDNF) plays a crucial role in mediating changes in learning and memory performance induced by environmental conditions. In order to ascertain whether BDNF modulates environmentally induced changes in exploratory behaviour, we examined mice carrying a deletion in one copy of the BDNF gene. Young heterozygous male BDNF knockout mice (BDNF+/-) and their wild-type (WT) controls were exposed to the enriched environment condition (EC) or the standard condition (SC) for 8 weeks. Exploratory behaviour was assessed in the open-field (OF) and hole-board (HB) test. Brains from EC and SC reared animals were processed for Golgi-Cox staining and the dendritic spine density in the dentate gyrus (DG) and CA1 hippocampal regions were examined. We found behavioural differences both due to the genetic modification and the environmental manipulation, with the BDNF+/- mice being more active in the OF whereas the EC mice had increased exploratory behaviour in the HB test. Environmental enrichment also led to an increase in dendritic spines in the hippocampal CA1 region and DG of the wild-type mice. This effect was also found in the enriched BDNF+/- mice, but was less pronounced. Our findings support the critical role of BDNF in behavioural and neural plasticity associated with environmental enrichment and suggest that besides maze learning performance, BDNF dependent mechanisms are also involved in other aspects of behaviour. Here we provide additional evidence that exploratory activity is influenced by BDNF.

**Veyrac, A., Sacquet, J., Nguyen, V., Marien, M., Jourdan, F., & Didier, A. (2008). Novelty Determines the Effects of Olfactory Enrichment on Memory and Neurogenesis Through Noradrenergic Mechanisms. *Neuropsychopharmacology,34*(3), 786-795. doi:10.1038/npp.2008.191**

Commonly used experimental paradigms of environmental enrichment combine increased social interactions and sensory inputs and renewal of the objects present in the environment. However, the specific contribution of novelty to the effects of enrichment is unclear. Here, we show that repeated daily exposure to single novel odorants and not to an enriched but stable olfactory environment improves short-term olfactory memory and neurogenesis in the mouse olfactory bulb. In addition, these positive effects are mediated by noradrenalin as they are blocked by a noradrenergic receptor antagonist. These data suggest that novelty recognition and noradrenergic mechanisms are crucial in mediating neural plasticity induced by olfactory enrichment.

**Kelsch, W., Lin, C., Mosley, C. P., & Lois, C. (2009). A Critical Period for Activity-Dependent Synaptic Development during Olfactory Bulb Adult Neurogenesis. *Journal of Neuroscience,29*(38), 11852-11858. doi:10.1523/jneurosci.2406-09.2009**

New neurons integrate in large numbers into the mature olfactory bulb circuit throughout life. The factors controlling the synaptic development of adult-born neurons and their connectivity remain essentially unknown. We examined the role of activity-dependent mechanisms in the synaptic development of adult-born neurons by genetic labeling of synapses while manipulating sensory input or cell-intrinsic excitability. Sensory deprivation induced marked changes in the density of input and output synapses during the period when new neurons develop most of their synapses. In contrast, when sensory deprivation started after synaptic formation was complete, input synapses increased in one domain without detectable changes in the other dendritic domains. We then investigated the effects of genetically raising the intrinsic excitability of new neurons on their synaptic development by delivering a voltage-gated sodium channel that triggers long depolarizations. Surprisingly, genetically increasing excitability did not affect synaptic development but rescued the changes in glutamatergic input synapses caused by sensory deprivation. These experiments show that, during adult neurogenesis in the olfactory bulb, synaptic plasticity is primarily restricted to an early period during the maturation of new neurons when they are still forming synapses. The addition of cells endowed with such an initial short-lived flexibility and long-term stability may enable the processing of information by the olfactory bulb to be both versatile and reliable in the face of changing behavioral demands.

**Benedetti, B. L., Glazewski, S., & Barth, A. L. (2009). Reliable and Precise Neuronal Firing during Sensory Plasticity in Superficial Layers of Primary Somatosensory Cortex. *Journal of Neuroscience,29*(38), 11817-11827. doi:10.1523/jneurosci.3431-09.2009**

Neocortical neurons show astonishing variation in the presence and timing of action potentials across stimulus trials, a phenomenon whose function and significance has been the subject of great interest. Here we present data showing that this response variability can be significantly reduced by altered sensory experience. Removal of all but one whisker from the side of the mouse face results in the rapid (within 24 h) potentiation of mean firing rates within the cortical representation of the spared whisker in young postnatal animals (postnatal days 13-16). Analysis of single-unit responses from whisker-spared animals shows that this potentiation can be attributed to an enhancement of trial-to-trial reliability (i.e., reduced response failures), as well as an increase in the mean number of spikes evoked within a successful trial. Changes were confined to superficial layers 2/3 and were not observed in the input layer of the cortex, layer 4. In addition to these changes in firing rates, we also observed profound changes in the precise timing of sensory-evoked responses. Trial-to-trial temporal precision was enhanced and the absolute latency of responses was reduced after single-whisker experience. Enhanced spike-timing precision and trial-to-trial reliability could also be triggered in adolescent animals with longer periods (7 d) of single-whisker experience. These experiments provide a quantitative analysis of how sensory experience can enhance both reliability and temporal precision in neocortical neurons and provide a framework for testing specific hypotheses about the role of response variability in cortical function and the molecular mechanisms underlying this phenomenon.

**Prior to 2009**

**Grubb, M., & Thompson, I. (2004). The influence of early experience on the development of sensory systems. *Current Opinion in Neurobiology,14*(4), 503-512. doi:10.1016/j.conb.2004.06.006**

Once sensory stimuli become able to alter firing patterns in the developing brain, they can influence the maturation of neuronal circuits. Recent experimental studies add to our understanding of precisely which developmental events are affected by early experience. In particular, it appears that experience of the external environment can affect the brain earlier in development and at earlier stages of sensory processing than previously thought. These studies emphasise the developmental importance of the patterning of neuronal firing produced either by sensory stimuli or by spontaneous activity. The timing of action potentials is also an important aspect of several exciting studies describing the mechanisms— anatomical, synaptic, and molecular — by which early experience brings about alterations in the maturation of sensory circuitry. Importantly, this kind of approach can lead to predictions concerning the nature of sensory stimulation that is most effective in instructing brain development.

**Lores-Arnaiz, S., Bustamante, J., Czernizyniec, A., Galeano, P., Gervasoni, M. G., Martínez, A. R., . . . Lores-Arnaiz, M. (2007). Exposure to enriched environments increases brain nitric oxide synthase and improves cognitive performance in prepubertal but not in young rats. *Behavioural Brain Research,184*(2), 117-123. doi:10.1016/j.bbr.2007.06.024**

Rats were randomly assigned to enriched (EE) or standard environments (SE) at 21 or 73 days of age, for 17 days. Half of the rats of each rearing condition were trained in a radial maze (RM). At 38 days (pre-pubertal) or 90 days (young), rats were sacrificed and brain cytosolic and mitochondrial nitric oxide synthase (mtNOS) activity was assayed. Western blot analysis of brain mtNOS was conducted. In the pre-pubertal group, EE rats improved their performance in the RM while SE rats did not. In the young group, SE and EE rats showed a random performance in the RM. In SE pre-pubertal rats, training increased brain cytosolic NOS and mtNOS activity by 68% and 82%. In EE non-trained pre-pubertal rats, brain cytosolic NOS and mtNOS activity increased by 80% and 60%, as compared with SE non-trained pre-pubertal rats. In EE pre-pubertal rats that were trained, brain cytosolic NOS and mtNOS activity increased by 70% and 90%, as compared with SE pre-pubertal rats that were not trained. A higher protein expression of brain mtNOS was found in EE rats, as compared with SE animals. Mitochondrial complex I activity was higher in EE than in SE rats. Training had no effect on complex I activity neither in SE nor in EE rats. In young rats, no significant differences in enzyme activities were found between EE and SE rats. These results support the hypothesis that brief exposure to EE and training produce effects on behavioral performance and on biochemical parameters in an age-dependent manner.

**Bark, K.   Wheeler, J.W.   Premakumar, S.   & Cutkosky, M.R (2008). Comparison of Skin Stretch and Vibrotactile Stimulation for Feedback of Proprioceptive Information.   This paper appears in: Haptic interfaces for virtual environment and teleoperator systems, 2008. haptics 2008. symposium 71-78.**

We present the results of experiments to compare vibration and skin stretch in a virtual proprioception task in which subjects used a force sensor to control the movement of a virtual aim. Pilot experiments pointed to the need to provide the arm with varying dynamics (like a real arm) and to scale the feedback from vibratory and skin stretch displays to demonstrate a clear improvement in the accuracy of movement. For the final experiments, ten subjects were first trained on the system with visual feedback and then tested with vibratory feedback, skin stretch feedback and no feedback. Both vibration and skin stretch improved the subjects' performance. For some subjects, a second no-feedback case showed improvement over the initial case, indicating learning; in other cases, the no- feedback performance deteriorated and subjects reported that they had become used to relying on feedback. Overall, skin stretch provided superior results, particularly when the virtual arm was in a low-inertia configuration and at low velocity. The results suggest that small skin-stretch devices could be worn on the body to provide useful proprioceptive information when interacting with virtual environments and in motion training for rehabilitation or sports.

**Sale, A., Cenni, M. C., Ciucci, F., Putignano, E., Chierzi, S., & Maffei, L. (2007). Maternal Enrichment during Pregnancy Accelerates Retinal Development of the Fetus. *PLoS ONE,2*(11). doi:10.1371/journal.pone.0001160**

The influence of maternal environment on fetal development is largely unexplored, the available evidence concerns only the deleterious effects elicited by prenatal stress. Here we investigated the influence of prenatal enrichment on the early development of the visual system in the fetus. We studied the anatomical development of the rat retina, by analyzing the migration of neural progenitors and the process of retinal ganglion cell death, which exerts a key role in sculpturing the developing retinal system at perinatal ages. The number of apoptotic cells in the retinal ganglion cell layer was analyzed using two distinct methods: the presence of pyknotic nuclei stained for cresyl violet and the appearance of DNA fragmentation (Tunel method). We report that environmental enrichment of the mother during pregnancy affects the structural maturation of the retina, accelerating the migration of neural progenitors and the dynamics of natural cell death. These effects seem to be under the control of insulin-like growth factor-I: its levels, higher in enriched pregnant rats and in their milk, are increased also in their offspring, its neutralization abolishes the action of maternal enrichment on retinal development and chronic insulin-like growth factor-I injection to standard-reared females mimics the effects of enrichment in the fetuses. Thus, the development of the visual system is sensitive to environmental stimulation during prenatal life. These findings could have a bearing in orienting clinical research in the field of prenatal therapy.

**Percaccio, C. R., Pruette, A. L., Mistry, S. T., Chen, Y. H., & Kilgard, M. P. (2007). Sensory experience determines enrichment-induced plasticity in rat auditory cortex. *Brain Research,1174*, 76-91. doi:10.1016/j.brainres.2007.07.062**

Our previous studies demonstrated that only a few days of housing in an enriched environment increases response strength and paired-pulse depression in the auditory cortex of awake and anesthetized rats [Engineer, N.D., Percaccio, C.R., Pandya, P.K., Moucha, R., Rathbun, D.L., Kilgard, M.P., 2004. Environmental enrichment improves response strength, threshold, selectivity, and latency of auditory cortex neurons. J Neurophysiol. 92, 73–82 and Percaccio, C.R., Engineer, N.D., Pruette, A.L., Pandya, P.K., Moucha, R., Rathbun, D.L., Kilgard, M.P., 2005. Environmental enrichment increases paired-pulse depression in rat auditory cortex. J Neurophysiol. 94, 3590–3600]. Multiple environmental and neurochemical factors likely contribute to the expression of this plasticity. In the current study, we examined the contribution of social stimulation, exercise, auditory exposure, and cholinergic modulation to enrichment-induced plasticity. We recorded epidural evoked potentials from awake rats in response to tone pairs and noise bursts. Auditory evoked responses were not altered by social stimulation or exercise. Rats that could hear the enriched environment, but not interact with it, exhibited enhanced responses to tones and increased paired-pulse depression. The degree to which enrichment increased response strength and forward masking was not reduced after a ventricular injection of 192 IgG-saporin. These results indicate that rich auditory experience stimulates physiological plasticity in the auditory cortex, despite persistent deficits in cholinergic activity. This conclusion may be beneficial to clinical populations with sensory gating and cholinergic abnormalities, including individuals with autism, schizophrenia, and Alzheimer's disease.

**Schmuckler, M. A., & Jewell, D. T. (2007). Infants visual-proprioceptive intermodal perception with imperfect contingency information. *Developmental Psychobiology,49*(4), 387-398. doi:10.1002/dev.20214**

Two experiments explored 5-month-old infants' recognition of self-movement in the context of imperfect contingencies between felt and seen movement. Previous work has shown that infants can discriminate a display of another child's movements from an on-line video display of their own movements, even when featural information is removed. These earlier findings were extended by demonstrating self versus other discrimination when the visual information for movement was an unrelated object (a fluorescent mobile) directly attached to the child's leg, thus producing imperfect spatial and temporal contingency information. In contrast, intermodal recognition failed when the mobile was indirectly attached to infants' legs, thus eliminating spatial contingencies altogether and further weakening temporal contingencies. Together, these studies reveal that even imperfect contingency information can drive intermodal perception, given appropriate levels of spatial and temporal contingency information.

**Kreppner, J. M., Rutter, M., Beckett, C., Castle, J., Colvert, E., Groothues, C., . . . Sonuga-Barke, E. J. (2007). Normality and impairment following profound early institutional deprivation: A longitudinal follow-up into early adolescence. *Developmental Psychology,43*(4), 931-946. doi:10.1037/0012-1649.43.4.93**

Longitudinal analyses on normal versus impaired functioning across domains were conducted in children who had experienced profound institutional deprivation up to the age of 42 months and were adopted from Romania into U.K. families. Comparisons were made with noninstitutionalized children adopted from Romania and with non-deprived within-U.K. adoptees placed before the age of 6 months. Specifically, the validity of the assessment, the degree of continuity and change in levels of functioning from 6 to 11 years, and the factors in the pre- and post-adoption environment accounting for heterogeneity in outcome were examined. Pervasive impairment was significantly raised in children experiencing institutional deprivation for =6 months of life, with a minority within this group showing no impairment. There was no additional significant effect of duration of deprivation beyond the 6-month cutoff, and few other predictors explained outcome. The pattern of normality/impairment was mainly established by 6 years of age, with considerable continuity at the individual level between 6 and 11 years. The findings are discussed in terms of the possibility of a sensitive period for development.

**Jiao, Y. (2006). Major Effects of Sensory Experiences on the Neocortical Inhibitory Circuits. *Journal of Neuroscience,26*(34), 8691-8701. doi:10.1523/jneurosci.2478-06.2006**

[During postnatal development, sensory experiences play cr](http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6SYR-4PCPFM5-K&_user=10&_coverDate=10%2F12%2F2007&_rdoc=1&_fmt=full&_orig=search&_cdi=4841&_sort=d&_docanchor=&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=43b9ed855236a03148aaf2c9e5f4ddbe#implicit0)it[icalroles in the refinement of cortical connec](http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6SYR-4PCPFM5-K&_user=10&_coverDate=10%2F12%2F2007&_rdoc=1&_fmt=full&_orig=search&_cdi=4841&_sort=d&_docanchor=&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=43b9ed855236a03148aaf2c9e5f4ddbe#implicit0)t[ions. However, boththe process of postnatal experience-dependent maturation ofneocortical inhibitory networks and its underlying mechanismsremain elusive. Here, we examined the differential propertiesof intracortical inhibitory networks of layer IV in "sensory-spared"and "sensory-deprived" cortices of glutamate acid decarboxylase67 (GAD67)–green fluorescent protein (GFP) ({Delta}neo) and wild-typemouse. Our results showed that row D whisker trimming (WT) begunat postnatal day 7 (P7), but not after P15, induced a robustreduction of parvalbumin (PV) expression, measured by the PV/GFPratio and PV cell densities, in the deprived barrels. WT alsoinduced a robust reduction in the number of inhibitory perisomaticvaricosities and synaptic GAD65/67 immunoreactivities in spinyneurons of the deprived barrels. Although the GAD65/67 expressionsin interneurons were also downregulated in the deprived barrels,the GFP expression remained unchanged. Patch-clamp recordingfrom spiny cells showed a 1.5-fold reduction of intracorticalevoked IPSCs (eIPSCs) in deprived versus spared cortices. Thereduction in eIPSCs occurred via changes in presynaptic propertiesand unitary IPSC amplitudes. Miniature IPSCs showed subtle butsignificant differences between the two experimental conditions.In addition, properties of the IPSCs in deprived barrels resemblethose of IPSCs recorded in immature brains (P7). Together, theseresults suggest that the properties of local intracortical inhibitorynetworks are modified by sensory experiences. Perisomatic inhibitionmediated by PV-positive basket cells is pruned by sensory deprivation.](http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6SYR-4PCPFM5-K&_user=10&_coverDate=10%2F12%2F2007&_rdoc=1&_fmt=full&_orig=search&_cdi=4841&_sort=d&_docanchor=&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=43b9ed855236a03148aaf2c9e5f4ddbe#implicit0)

**Hay, L., Bard, C., Ferrel, C., Olivier, I., & Fleury, M. (2005). Role of proprioceptive information in movement programming and control in 5 to 11-year old children. *Human Movement Science,24*(2), 139-154. doi:10.1016/j.humov.2005.05.002**

This study investigated the role of proprioceptive sensations in the control of hand movements towards specific targets. The subjects consisted of four groups of boys and girls: fifteen 5-year olds, thirteen 7-year olds, twelve 9-year olds, and twelve 11-year olds. They performed a serial pointing task by alternating wrist flexion and extension. They made movements of various amplitudes and various positions using a pointer. Under the experimental conditions, the subjects received tendon vibration to the wrist flexors and extensors either while stopped at the targets or while moving towards the targets. The vibration altered the proprioceptive information. Additionally during the experimental phases the children did not receive visual feedback of their movements or pointing errors. The application of vibration during motion led to an increased constant error of reduced movement amplitude in all age groups and position error in the direction of the movement starting point. The distortion of proprioceptive input during the static phases before movement increased the variable amplitude error, with the greatest negative effect on 5-year old children performing extension movements. The conclusions were that: there are 1) developmental trends in the weighted use of proprioceptive input in the feedforward and feedback based components of movement control in children, 2) changes that include an improved ability to shift from one strategy to another, dependent upon the incoming sensory information, and 3) developmental trends indicating alternating mastery of different approaches to control of amplitude and position leading to eventual integrated use of the approaches. More specifically, the 5-year old children relied primarily on a ballistic-like type of movement control governed by the spatial reference of the hand starting position; the 7- and 9-year old children depend more on vision to direct their hand movements and spatial calibration of hand position during movement; and the 11-year old children were best at congruently controlling for both amplitude and spatial movement parameters.

**SIGN note**: This study provides information about the developmental trends in typical children relative to the use of proprioceptive sensations to direct hand movements. The findings could expand Ayres’ SI theory on the effects of vision and proprioception on praxis.

Reviewed by Katherine Inamura, 11/18/2005

**Restivo, L., Ferrari, F., Passino, E., Sgobio, C., Bock, J., Oostra, B. A., . . . Ammassari-Teule, M. (2005). Enriched environment promotes behavioral and morphological recovery in a mouse model for the fragile X syndrome. *Proceedings of the National Academy of Sciences,102*(32), 11557-11562. doi:10.1073/pnas.0504984102**

Fragile X syndrome, the most frequent form of hereditary mentalretardation, is due to a mutation of the fragile X mental retardation1 (*FMR1*) gene on the X chromosome. Like fragile X patients,*FMR1*-knockout (*FMR1*-KO) **mice** lack the normal fragile X mentalretardation protein (FMRP) and show both cognitive alterationsand an immature neuronal morphology. We reared *FMR1*-KO **mice**in a C57BL/6 background in enriched **environmental** conditionsto examine the possibility that experience-dependent stimulationalleviates their behavioral and neuronal abnormalities. *FMR1*-KO**mice** kept in standard cages were hyperactive, displayed an alteredpattern of open field exploration, and did not show habituation.Quantitative morphological analyses revealed a reduction inbasal dendrite length and branching together with more immature-appearingspines along apical dendrites of layer five pyramidal neuronsin the visual cortex. **Enrichment** largely rescued these behavioraland neuronal abnormalities while increasing {alpha}-amino-3-hydroxy-5-methyl-4-isoxazolepropionicacid (AMPA) glutamate receptor subunit 1 (GluR1) levels in bothgenotypes. **Enrichment** did not, however, affect FMRP levels inthe WT **mice**. These data suggest that FMRP-independent pathwaysactivating glutamatergic signaling are preserved in *FMR1*-KO**mice** and that they can be elicited by **environmental** stimulation.

**Sober, S. J. & Sabes, P. N. (2005). Flexible strategies for sensory integration during motor planning. *Nature Neuroscience*, 8(4), 490-497. doi:10.1038/nn1427**

This study investigated the process of combining visual and proprioceptive feedback to create two estimates of the arm’s position for planning target-directed movements. One estimate is used for movement vector planning and the other is for conversion of the direction into a motor command. The first experiment involved 5 female and 2 male subjects, 18 – 34 years of age. The subjects made planar reaching movements on a horizontal table with virtual visual feedback to either a visual target (spot of light) or a proprioceptive target, (felt position of left index fingertip). The visual feedback was eliminated as the subject began to reach. The second experiment included 5 female and 5 male subjects, 18 – 34 years of age. The subjects made the reaching movements to visual targets and received feedback of either a spot indicating fingertip position or simple virtual image of the arm. The researchers interpreted the results of the experiments to be evidence that the brain weights visual and proprioceptive input according to the sensory modality of the target and the information content of the visual feedback. The planning of the reach direction is more dependent upon visual information and creation of the motor command is more dependent upon proprioceptive information. The researchers postulated that the variability in the weightings was to reduce errors related to the transformation of sensory signals between coordinate frames.

**SIGN note**: This study provides information about the integration of proprioceptive and visual sensations to direct hand movements in adults. The findings could expand Ayres’ SI theory on the effects of vision and proprioception on praxis.

Reviewed by Katherine Inamura, 1/28/2006

**Soto-Faraco, S., Ronald, A., & Spence, C. (2004). Tactile selective attention and body posture: assessing the multisensory contributions of vision and proprioception. *Perception & Psychophysics*, 66 (7), 1077-1094. doi:10.3758/bf03196837**

This study evaluated the effects of proprioceptive and visual cues concerning arm/hand posture on tactile spatial attention. Five experiments were performed utilizing small groups (n = 8-10 male and female college students). In each experiment the subjects were required to speedily report if the continuous vibrotactile stimulus was being received either by the thumb or index finger (either in an up or down position) on one hand while a digit (either thumb or index finger) on the other hand was receiving a pulsed vibrotactile distractor stimulus. The first four experiments were conducted in a darkened room to eliminate visual cues. The first two experiments indicated that the subjects could not ignore the distractor stimulus to the non-target hand. The interference effect was greatest when the hand to receive the target stimulus was uncertain. The results suggested that people could direct their spatial attention to a particular hand when the target hand was known in advance and that this focusing of attention improved the processing of the target stimulation. The findings also indicated that the shifting of attention across the body surface to orient to a target stimulus requires time. The third experiment involved varying the posture of the hands (i.e., hand/wrist up or down, in different combinations). It was found that the perception of the target stimulus was effected by the position of the target and distractor in external space or relative to some part of the body. The fourth experiment contrasted the effects of the proprioceptive inputs of a hands-near position and hands-far position. The interference effect of the distractor stimulus was greatest when the hands were in the near position. These latter two studies supported the postulate that tactile spatial attention is based on an abstract frame of reference (either based egocentrically or externally). For the final experiment the subjects placed one arm close to the body midline and the other arm extended away from their trunk. For half of the trials for each participant, a mirror was used so that the two arms appeared to be close together although the arms actually were not close. The interference effect from the distractors was higher when the arms visually appeared to be closer together. This result suggests that the integration of the visual information was automatically integrated with the tactile and proprioceptive input. The researchers interpreted the studies’ results to suggest that multisensory integration of tactile, visual, and proprioceptive information occurs prior to tactile selective attention. Furthermore, they suggest that as a person assumes different body postures there is a reconfiguration of tactile spatial information based on the information from muscle position and gravitational forces to aid in accurate perception of touch stimuli in space. However, the body representation may not be error-free and time is required to improve its preciseness.

**SIGN note**: The study’s findings contribute to the understanding of how visual, proprioceptive, and tactile input is integrated to assist in attention to and interpretation of localized tactile sensations, important in Ayres’ SI theory. This information could be helpful in refining tests of tactile perception. It also seems to lend support for the principle of providing varied, multi-sensory enriched activities to promote better integration of sensory information.

Reviewed by Katherine Inamura, 11/18/2005

**N. Benaroya-Milshtein, N. Hollander, A. Apter, T. Kukulansky, N. Raz, A. Wilf, I. Yaniv, & C.G. Pick (2004). Environmental enrichment in mice decreases anxiety, attenuates stress responses and enhances natural killer cell activity. *European Journal of Neuroscience 20*, 1341–1347. doi:10.1111/j.1460-9568.2004.03587.x**

[The importance of environment in the regulation of brain, behaviour and physiology has long been recognized in biological, social and medical sciences. Animals maintained under enriched conditions have clearly been shown to have better learning abilities than those maintained under standard conditions. However, the effects of environmental enrichment (EE) on immunity and emotionality have been less documented and remain questionable. Therefore, we investigated the effect of EE on natural killer (NK) cell activity, psychological stress responses and behavioural parameters. Male C3H mice were housed either in enriched or standard conditions for 6 weeks. Behaviour was then examined by the grip-strength test, staircase and elevated plus maze, and corticosterone levels and NK cell activity were measured. Furthermore, animals exposed to the stress paradigm, achieved by electric shock with reminders, were tested for freezing time in each reminder. Corticosterone levels were also measured. The EE mice showed decreased anxiety-like behaviour and higher activity compared to standard mice, as revealed by a greater percentage of time spent in the open arms of the elevated plus maze, and a higher rate of climbing the staircase. A shorter freezing time in the stress paradigm and no corticosterone level reactivity were measured in EE mice. In addition, NK cell activity in spleens of EE mice was higher than that demonstrated in those of standard mice. Thus, EE has a beneficial effect on anxiety-like behaviour, stress response and NK cell activity. The effect on NK cell activity is promising, due to the role of NK cells in host resistance.](http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6SYR-4PCPFM5-K&_user=10&_coverDate=10%2F12%2F2007&_rdoc=1&_fmt=full&_orig=search&_cdi=4841&_sort=d&_docanchor=&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=43b9ed855236a03148aaf2c9e5f4ddbe#implicit0)

**Engineer, N.D., Percaccio, C.R., Pandya, P.K., Moucha, R., Rathbun D.L. & Kilgard, M.P. (2004). Environmental Enrichment Improves Response Strength, Threshold, Selectivity, and Latency of Auditory Cortex Neurons *Journal of Neurophysiology, 92,* 73-82. doi:10.1152/jn.00059.2004**

Over the last 50 yr, environmental enrichment has been shownto generate more than a dozen changes in brain anatomy. Theconsequences of these physical changes on information processinghave not been well studied. In this study, rats were housedin enriched or standard conditions either prior to or afterreaching sexual maturity. Evoked potentials from awake ratsand extracellular recordings from anesthetized rats were usedto document responses of auditory cortex neurons. This reportdetails several significant, new findings about the influenceof housing conditions on the responses of rat auditory cortexneurons. First, enrichment dramatically increases the strengthof auditory cortex responses. Tone-evoked potentials of enrichedrats, for example, were more than twice the amplitude of ratsraised in standard laboratory conditions. Second, cortical responsesof both young and adult animals benefit from exposure to anenriched environment and are degraded by exposure to an impoverishedenvironment. Third, housing condition resulted in rapid remodelingof cortical responses in <2 wk. Fourth, recordings made underanesthesia indicate that enrichment increases the number ofneurons activated by any sound. This finding shows that theevoked potential plasticity documented in awake rats was notdue to differences in behavioral state. Finally, enrichmentmade primary auditory cortex (A1) neurons more sensitive toquiet sounds, more selective for tone frequency, and alteredtheir response latencies. These experiments provide the firstevidence of physiologic changes in auditory cortex processingresulting from generalized environmental enrichment.

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Thus far, the developmental plasticity of the visual system has been studied by altering or reducing visual experience. Here, we investigated whether a complex sensory-motor stimulation, provided by rearing animals in an enriched environment, affects visual system development. We found that raising mice in this condition causes an earlier eye opening, a precocious development of visual acuity, and an accelerated decline of white matter-induced long-term potentiation. These effects are accompanied by a precocious cAMP response element-mediated gene expression and a significant increase of BDNF protein and GAD65/67 expression in enriched pups. In addition, we showed that enriched pups experienced higher levels of licking behavior provided by adult females. Thus, rearing mice from birth in an enriched environment leads to a conspicuous acceleration of visual system development as ascertained at behavioral, electrophysiological, and molecular level.

**Morley-Fletcher, S., Rea, M., Maccari, S., & Laviola, G. (2003). Environmental enrichment during adolescence reverses the effects of prenatal stress on play behaviour and HPA axis reactivity in rats. *European Journal of Neuroscience,18*(12), 3367-3374. doi:10.1111/j.1460-9568.2003.03070.x**

Prenatal stress (PS) can produce profound and long-lasting perturbations of individual adaptive capacities, which in turn can result in an increased proneness to behavioural disorders. Indeed, in PS rats there is evidence of impaired social play behaviour, disturbances in a variety of circadian rhythms**,** enhanced anxiety and increased hypothalamic–pituitary–adrenal (HPA) axis reactivity. This study was designed to experimentally investigate the degree of reversibility of PS-induced disturbances of social play and HPA reactivity by assessing the effect of the enrichment of the physical environment on PS rats during periadolescence. PS subjects showed a reduced expression of social play behaviour and a prolonged corticosterone secretion in response to restraint stress, but both these effects were markedly reversed following environmental enrichment. Interestingly, the enrichment procedure increased social behaviour but had no effect on corticosterone secretion in nonstressed animals, indicating a differential impact of the postnatal environment as a function of prenatal background. As a whole, results clearly indicate that rats prenatally exposed to stress can benefit during periadolescence from the modulatory effects of an enriched environment. Moreover, they confirm that PS may well represent a suitable animal model for the design and testing of new therapeutic strategies for behavioural disorders produced by early insults

**Brown, J., Cooper-Kuhn, C. M., Kempermann, G., Praag, H. V., Winkler, J., Gage, F. H., & Kuhn, H. G. (2003). Enriched environment and physical activity stimulate hippocampal but not olfactory bulb neurogenesis. *European Journal of Neuroscience,17*(10), 2042-2046. doi:10.1046/j.1460-9568.2003.02647.x**

Exposure to an enriched environment and physical activity, such as voluntary running, increases neurogenesis of granule cells in the dentate gyrus of adult mice. These stimuli are also known to improve performance in hippocampus-dependent learning tasks, but it is unclear whether their effects on neurogenesis are exclusive to the hippocampal formation. In this study, we housed adult mice under three conditions (enriched environment, voluntary wheel running and standard housing), and analysed proliferation in the lateral ventricle wall and granule cell neurogenesis in the olfactory bulb in comparison to the dentate gyrus. Using bromodeoxyuridine to label dividing cells, we could not detect any difference in the number of newly generated cells in the ventricle wall. When giving the new cells time to migrate and differentiate in the olfactory bulb, we observed no changes in the number of adult-generated olfactory granule cells; however, voluntary running and enrichment produced a doubling in the amount of new hippocampal granule cells. The discrepancy between the olfactory bulb and the dentate gyrus suggests that these living conditions trigger locally through an as yet unidentified mechanism specific to neurogenic signals in the dentate gyrus.

**Francis, D. D., Diorio, J., Plotsky, P. M., & Meaney, M. J. (2002). Environmental Enrichment Reverses the Effects of Maternal Separation on Stress Reactivity. *The Journal of Neuroscience,22*(18), 7840-7843. doi:10.1523/jneurosci.22-18-07840.2002**

Postnatal maternal separation increases hypothalamic corticotropin-releasing factor (CRF) gene expression and hypothalamic-pituitary-adrenal(HPA) and behavioral responses to stress. We report here that**environmental** **enrichment** during the peripubertal period completely**reverse**s the effects of maternal separation on both HPA and behavioralresponses to stress, with no effect on CRF mRNA expression. Weconclude that **environmental** **enrichment** leads to a functional reversalof the effects of maternal separation through compensation for,rather than reversal of, the neural effects of early lifeadversity.

**Florence, S. L., Boydston, L. A., Hackett, T. A., Lachoff, H. T., Strata, F., & Niblock, M. M. (2001). Sensory enrichment after peripheral nerve injury restores cortical, not thalamic, receptive field organization. *European Journal of Neuroscience,13*(9), 1755-1766. doi:10.1046/j.0953-816x.2001.01555.x**

These authors examined the effect of providing sensory enrichment experiences to 6 macaque monkeys after inducing a median nerve cut and repair early in life. One of these macque monkeys received a nerve cut, however, was restrained from using the hand, therefore resulting in not receiving any enriched sensory experiences. Multiunit microelectrodes were used to map the sensory representation of the hand in the primary somatosensory cortex. The somatosensory relay in the thalamus and the ventroposterior nucleus was also studied to determine if the sensory enrichment experience was initiated subcortically or cortically. It was found that rehabilitation involving sensory retraining could improve perceptual function, most probably through plasticity in the somatosensory processing network in the brain. The effect of sensory enrichment was found to be cortically related with the most significant effect on the receptive field sizes in the cortical area 3b. It was found that sensory rehabilitation after nerve regeneration can significantly improve sensory perception and changes in map organization after an injury, however, it does not completely produce normal maps of the hand representation. The effects of sensory enrichment on the functional organization of cortical area 3b is an important component that leads to more improved perceptual outcomes as a function of rehabilitation after a nerve injury.

**Praag, H. V., Kempermann, G., Gage, F.H. (2000). Neural Consequences of Environmental Enrichment. *Macmillan Magazines LTD, 1* , 191-198. doi:10.1038/35044558**

This review paper examines the neuronal changes that occur in reaction to complex stimulation by an enriched environment. More specifically, the authors of this study focuses on the impact of certain elements of enrichment, including exercise and learning, on behavior and neurobiology. The paper reviews a variety of different studies (primarily of rats) that support the following: First, environmental enrichment has been shown to enhance spatial memory and exercise enhances spatial learning. Second, environmental enrichment enhances cell survival and exercise enhances cell proliferation. Third, research has shown that motor skill learning, through exercise, may lead to increased cortical thickness and synaptogenesis. Fourth, living in an enriched environment that integrates exercise may lead to higher levels of growth factors, which may impact learning and synaptic plasticity. Fifth, an enriched environment that integrates exercise has been shown to result in an increase in neurotransmitters, such as acetylcholine. Finally, enriched environments have been shown to facilitate a recovery in damaged or diseased brains, e.g. a brain that has suffered a stroke. However, additional research needs to be conducted in order to determine if these positive effects are long lasting.

**Van Praag, H., Kempermann, G. &  Gage, F.H. (1999). Running increases cell proliferation and neurogenesis in the adult mouse dentate gyrus. Nature Neuroscience  2, 266 – 270. doi:10.1038/6368**

Exposure to an enriched environment increases neurogenesis in the dentate gyrus of adult rodents. Environmental enrichment, however, typically consists of many components, such as expanded learning opportunities, increased social interaction, more physical activity and larger housing. We attempted to separate components by assigning adult mice to various conditions: water-maze learning (learner), swim-time-yoked control (swimmer), voluntary wheel running (runner), and enriched (enriched) and standard housing (control) groups. Neither maze training nor yoked swimming had any effect on bromodeoxyuridine (BrdU)-positive cell number. However, running doubled the number of surviving newborn cells, in amounts similar to enrichment conditions. Our findings demonstrate that voluntary exercise is sufficient for enhanced neurogenesis in the adult mouse dentate gyrus.