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Intermanual and Intermodal Transfer in Human Newborns: Neonatal Behavioral Evidence and Neurocognitive Approach

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1. Introduction

Until recently, newborns had typically been described as displaying mainly involuntary reactions and clumsy arm movements. However, in recent years investigation of exploratory perception of objects has emerged as key area research. Newborns' hands have often been described as closed or exhibiting either grasping or avoidance reactions which are inappropriate behaviors for holding an object and gathering and processing information (Katz, 1925; Roland and Mortensen 1987; Twitchell, 1965). However, besides possessing manual brief reactions (reflex), newborns are also able to handle small objects and to perceive their properties. To reveal this tactile ability, researchers have applied a habituation-dishabituation procedure to the tactile modality, just as in the visual modality (Streri & Pêcheux, 1986a). This procedure, which is controlled by the infant, is effective in revealing the early perceptual capacities of young babies (cf. Streri, 1993). It unfolds in two phases. The first phase, habituation, includes a series of trials in which the infants receive a small object in one hand. A trial begins when the infant holds the object and ends when the infant drops it or after a maximum duration defined by the experimenter. This process is repeated several times. As a consequence, the habituation process entails several grasps of determined duration (usually between 1 sec to 60 sec of holding). Trials continue until the habituation criterion is met. The newborn is judged to have been habituated when the duration of holding on any two consecutive trials, from the third onwards, totals a third (or a quarter, depending on age) or less of the total duration of the first two trials. Total holding time is taken as an indicator of the duration of familiarization. The mean number of trials taken to reach habituation ranges from four to twelve, and often varies with shape complexity. The decrease in holding times is considered to reveal the infants' ability to perceive and form a memory of the shape and subsequently recognize it. Then, in the dishabituation phase, a novel object is put in the infant's hand. If an increase in holding time of the novel object is observed, it is inferred that the baby is reacting to novelty, having noticed the difference between novel and familiar objects. That these processes reveal a form of mental representation of stimuli is now well established (cf. Pascalis & De Haan, 2003; Rovee-Collier & Barr, 2001).

Using this experimental procedure, Streri, Lhote, and Dutilleul (2000) showed that full-term newborns (the youngest was 16 hours old) were able to detect differences in the contours of

two small objects (a smoothly curved cylinder versus a sharply angled prism) with both right and left hands. After habituation with one of the two objects placed in the right or left hand, the newborns reacted to novelty when a new object (the prism or cylinder) was put in their hand. This was the first evidence of habituation and reaction to novelty observed with the left as well as the right hand in human newborns. Thus, newborns are able to discriminate between curvilinear and rectilinear contours in small objects. However, this behavior does not show that babies have a clear representation of what they are holding in their hand. Because young infants are unable to perform the integration and synthesis of information in working memory required for haptic exploration, their shape perception is probably partial or limited to the detection of clues such as points, curves, presence or absence of a hole, etc. The information gathered is provided by the enclosure of the object (cf. Lederman & Klatzky, 1987), which seems to be an effective exploratory procedure for these limited purposes. To understand the emergence of these manual abilities in full-term newborns, it is important to recall the early maturation of touch (first among the senses to begin functioning) in the foetal period (from a cephalo-caudal point of view). Tactile receptors can be found in the epithelium of the mouth and the dermis of the peri-oral area as early as 8-9 gestational weeks. Meissner and Pacini corpuscles develop soon after. Tactile receptors are found on the face, the palms and the soles of the feet by 11 weeks. By the 15th week they are found on the trunk and proximal zones of arms and legs, and on the whole skin by the 20th week (Humphrey, 1964). Taken together, these data suggest that this ability to perceive various shapes with both hands observed in full-term newborns may be a "core ability" already present in the foetus. To investigate this hypothesis, the study of this manual ability in preterm babies is relevant and may reveal continuity in sensory functioning between foetal and neonatal periods, by determining whether preterm babies are able to extract information with their hands.

The current World Health Organization definition of premature is a baby born before 37 weeks of gestation, counting from the first day of the last menstrual period, where 40 weeks of gestation is the normal term. Moreover, the viability of foetuses is between 22 and 24 weeks of gestation, depending on the country. Studies about preterm babies and touch have generally focused on pain and developmental concerns (Sizun & Browne, 2005). They have shown that neonates' pain responses are influenced by the number of painful procedures previously experienced by the infant (Johnston & Stevens, 1996). Bartocci, Bergqvist, Lagercrantz and Anand (2006) showed that tactile and painful stimuli specifically activate somatosensory cortical areas. This result indicates that central integration of tactile information occurs in preterm newborns at 28-36 weeks of gestation. A link between hand movements and somatosensory cortical activation has also been shown in preterm newborns at 29-31 weeks of gestation (Milh *et al.*, 2007). Recently, Lejeune, Audéoud, Marcus, Streri, Debillon and Gentaz (2010) investigated the ability of preterm babies' hands to discriminate between various shapes. Twenty-four preterm babies underwent a habituation phase followed by a test phase. The entire observation is performed in such a way the newborns cannot see their hands and the held object. In the test phase, twelve babies (experimental group) were tested with a novel object whereas twelve babies (control group) were tested with a familiar object (the one presented during the habituation phase). The shapes used were similar to those used by Streri *et al* (2000): a cylinder and a prism with identical object/hand surface ratio. These objects were smaller than those used by Streri *et al.* (2000) because preterm babies' hands are smaller than those of full term babies. The

results revealed that when an object is placed in a preterm newborn's hand, holding time decreases trial by trial until the habituation criterion is reached. In the test phase, the experimental group held the novel object significantly longer compared to the preceding two habituation trials, in contrast to the control group in which this was not the case. These results suggest that preterm babies react differentially to a novel shape. These findings are in accordance with the early maturation of touch.

Taken together, these results show that preterm and full-term babies are able to memorize the shape of an object with each hand. These abilities reflect the very early existence of some internal representation of a stimulus. However, what is the nature of this internal representation? If it has some level of abstraction, newborns should be able to transfer object information from one hand to the other (low level of abstraction) or from one hand to the visual modality (high level of abstraction). Thus, the first goal of this chapter was to show that full-term and preterm newborns are capable of transferring shape and texture information from one hand to the other. The second goal was to show that full-term newborns are capable of transferring information between touch and vision in some, but not all, conditions. These limits or failures may be explained by neuroimaging evidence in adults.

2. Intermanual perception of object shape in human newborns

One reason for interest in intermanual transfer is its potential value in assessing communication between the two hemispheres and cerebral plasticity during cognitive development. Sann and Streri (2008a) investigated the inter-manual transfer of shape in twenty-four 2-day-old full-term newborns. After tactual habituation to a shape (prism or cylinder) in one hand, full-term newborns held the familiar shape longer in the opposite hand, and not the novel shape as usually expected in such procedure (Soroka, Corter, & Abramovitch, 1979). But in the same study, infants also exhibited inter-manual transfer of texture (smooth or granular), with a preference for the novel texture in the opposite hand. According to Sann and Streri (2008a), these discrepancies in performance between object properties indicate that the property of shape requires a more abstract and elaborate representation relative to texture. However, given the design of the study, it is not possible to draw definite conclusions about the type of shape information that was transferred: the entire shape of the object, edge information (round vs. angled), or other contrasts or differences. Regardless, these results provided evidence of intermanual transfer of shape in full-term newborns, confirming the hypothesis that the development of the corpus callosum at this stage is sufficient to permit some transfer of shape information between the two hands. Indeed, an fMRI study has demonstrated the essential contribution of posterior corpus callosum to the inter-hemispheric transfer of tactile information (Fabri et al., 2001, 2005).

Considering that the corpus callosum is less mature in preterm infants than full-term infants (Anderson, Laurent, Woodward, & Inder, 2006) and that very preterm birth (before 33 GW) may be associated with perinatal brain injury including the corpus callosum (Kontis et al., 2009), Lejeune et al. (in press) explored whether preterm infants are capable of inter-manual transfer of shape after the age of 33 GW. Using a classic tactile habituation-dishabituation procedure the authors predicted that after successive presentations of the same object, each preterm infant would show a decrease in holding time regardless of the hand tested or

object shape. Second, the hypothesis of discrimination in intermanual transfer would be confirmed by differential treatment of novel and familiar objects in the opposite hand, as demonstrated previously in full-term newborns (Sann & Streri, 2008a). Thus, discrimination would be considered to have occurred when mean holding time for novel and familiar objects in the opposite hand differed significantly. Firstly, the results confirmed the occurrence of haptic manual habituation for each hand and for each shape in preterm infants between 33 and 34+6 GW. The second and main result was that, after habituation to the shape of an object in one hand, preterm infants held the novel object longer in the opposite hand.   These results revealed intermanual transfer of shape in preterm infants between 33 and 34+6 GW for the first time. Fabri et al. (2005) showed the essential contribution of posterior corpus callosum to the inter-hemispheric transfer of tactile information: its development thus seems to be sufficient to permit the transfer of some shape information between hands in preterm infants between 33 and 34+6 GW. However, preterm infants' holding time in the opposite hand increased with both novel and familiar objects, although this increase was significantly greater for the novel object than for the familiar one. While the increase in holding time was expected for the novel object, confirming the presence of discrimination, the increase in holding time for the familiar object was more surprising. This second result relates to the influence of changing hands on manual discrimination. This pattern of results could be due to two factors, one peripheral and one central. At a peripheral level, the tactile receptors were not the same as those stimulated during habituation and the information collected by the opposite hand had to be sent to the central nervous system by another pathway. In addition, given that the infant participants had underdeveloped muscle tone, the increase in holding time could also be caused by muscle fatigue in the habituated hand, compared to the unfatigued contralateral hand. Any form of tactile stimulation of the contralateral hand would induce some degree of recovery from habituation. At a central level, comparing objects information collected from the two hands may require more time than during an intramanual discrimination. This increase in holding time could reflect the time required to transfer information between the two hemispheres via the corpus callosum.

Finally, the direction of preference (preference for novelty) differed from that observed in 2-day-old full-term newborns with a similar procedure. Lejeune et al. (in press) propose two interpretations for this difference. First, because it is impossible to determine what type of shape information was transferred (entire shape, edge information or other contrasts or differences), one possible interpretation could be that full-term and preterm infants extract different types of shape information, leading to this discrepancy of preference. A second interpretation could be that experience prevails over maturation. Preterm infants were tested at a lower post-conceptional age (34+3 GW) than full-term newborns (40+2 GW) but at a higher postnatal age (30 days *vs.* 2 days). Consequently, the results could be explained by a greater tactile experience *ex utero* than for the full-term newborns. However, 2-month-old full-term infants have also been found to demonstrate a familiar preference (Streri, Lemoine, & Devouche, 2008) even though their postnatal age was higher than that of our preterm infants. A second factor that could explain this second discrepancy is the type of tactile experience which, combined with the length of experience, might influence the direction of preference. Preterm infants in their incubators receive a great deal of repetitive and stereotyped tactile stimulations (daily care, feeding, medical examinations, etc.). Hospitalized infants experience up to 14 painful procedures per day and up to 53 different

procedures during their first 15 days of life (Simons et al., 2003). Furthermore, Gimenez et al. (2008) showed that the maturation of brain tissue may be accelerated by factors associated with preterm birth, perhaps through the direct effects of the extrauterine environment. These particular tactile experiences could enhance the development of the intermanual transfer of information in preterm infants, even among younger infants who are at least 9 days old. In this case, according to the hypothesis proposed by Sann and Streri (2008a), preterm infants could have a more elaborate representation of shape than full-term newborns, leading to a preference for the novel shape in the opposite hand. However, these interpretations remain entirely speculative and post-hoc and require further investigation. More generally, the explanation of direction of preference is still debated in the infant studies literature, and seems to depend on several factors (e.g., Kerzerho, Streri, Gentaz, 2009; cf. Pascalis & De Haan, 2003). A preference indicates the presence of discrimination, whatever its direction, and suggests that the development of the corpus callosum is sufficient to permit some transfer of shape information between the two hands in preterm infants from 33 GW.

In conclusion, these results show that intermanual transfer of shape information is present at 33 GW in preterm infants. The occurrence of these intermanual abilities in full-term and preterm newborns suggests that some internal representation of a stimulus already has some level of abstraction. A second set of findings in favor of the existence of a higher-level internal representation stems from cross-modal studies on vision and touch in newborns.

3. Cross-modal transfer between touch and vision

In cognitive psychology, amodal perception is usually considered to be present at birth (see Streri, in press; Streri & Gentaz, 2009) as suggested by E. J. Gibson (1969). Beyond the details provided by individual sensory modalities, newborns are able to perceive a multimodal object as unified. However, the links between the haptic and the visual modalities are not fully established and will not be it until about the age of 15 years. Because newborns cannot engage in bimodal visual-haptic exploration of an object, a cross-modal transfer paradigm can be used to uncover the nature of these links and thereby evaluate young infants' ability to match the same object property captured by two modalities. However, cross-modal transfer tasks involve two successive phases (familiarization with an object in one modality and recognition test in a second modality). These tasks require cognitive processes (manual and visual information-processing capacities, memory load, etc.) that can weaken the links between sensory modalities and reveal failures in the establishment of amodal perception. Here we present a series of studies that illustrate these constraints.

3.1 Initial evidence in newborns

Newborns' visual abilities are weak. Nevertheless, numerous studies have revealed that babies can perceive speaking faces, photographs, objects, pictures, discriminate between large numbers, etc. (Coulon, Guellai and Streri, 2011; Féron, Gentaz, and Streri 2006; Guellai and Streri, 2011; Izard, Sann, Spelke and Streri, 2009; Meary, Kitromilides, Mazens, Graff and Gentaz, 2007; cf. Kellman and Arteberry, 1988, for a review). As discussed above, various studies have provided evidence that newborns are able to detect differences between shapes and textures with their hands (Streri et al. 2000; Molina and Jouen, 1998). All of these findings show that the prerequisites in both modalities are present to obtain cross-modal transfer between these senses.

Streri and Gentaz (2003; see also Streri and Gentaz, 2004) conducted an experiment on crossmodal transfer of shape information from the right hand to the eyes in 24 human newborns (mean age: 62 hours). They used an intersensory paired-preference procedure that included two phases: a haptic familiarization phase in which newborns were given an object to explore manually without seeing it, followed by a visual test phase in which infants were shown the familiar object paired with a novel one. Tactile objects were a small cylinder (10 mm in diameter) and a small prism (10 mm triangle base). Because the vision of newborns is immature and their visual acuity is weak, visual objects were the same 3D shapes, but much larger (45mm triangle base and 100mm in length for the prism and 30mm in diameter and 100mm in length for the cylinder). An experimental group (12 newborns) underwent the two phases successively (haptic then visual) whereas a baseline group (12 newborns) underwent only the visual test phase with the same objects as the experimental group but without haptic familiarization. Comparison of looking times between the two groups provided evidence of crossmodal recognition, with shapes explored by the hands of the experimental group recognized by the eyes. The newborns in the experimental group looked at the novel object for longer than the familiar one. In contrast, the newborns in the baseline group looked equally at both objects. Moreover, infants in the experimental group made more gaze shifts toward the novel object than the familiar object. In the baseline group this was not the case. Thus, this recognition in the experimental group stems from the haptic habituation phase. These results suggest that newborns recognized the familiar object through a visual comparison process as well as a comparison between the haptic and visual modalities. Moreover, the discrepancy between the sizes of the visual and tactile objects was apparently not relevant for crossmodal recognition. Shape alone seems to have been considered by newborns.

3.2 Limits of cross-modal shape transfer

Sann and Streri (2007) tested transfer from eyes to hand and from hand to eyes in order to ascertain whether this would demonstrate a complete primitive 'unity of the senses.' After haptic habituation to an object (cylinder or prism), the infants were shown the familiar and the novel shape in alternation. After visual habituation with either the cylinder or the prism, the familiar and the novel shape were put in the infant's right hand. The tactile objects were presented sequentially in an alternating manner. Again, visual recognition was observed following haptic habituation, but the reverse was not the case: no haptic recognition was found following visual habituation. Evidence of a visual recognition of shape also depended on the hand stimulated during the familiarization phase. No evidence of crossmodal recognition was found when the left hand was stimulated (Streri and Gentaz, 2004). Thus, cross-modal transfer seems not to be a general property of the newborn human; instead it is specific to certain parts of the body.

To understand this lack of bi-directional crossmodal transfer we must examine the differences between the ways that the two modalities process object shape. Vision processes shapes in a global manner, whereas touch processes information sequentially. Moreover, infants do not use efficient tactile exploratory procedures such as "*contour following*" to establish good representations of shapes (Lederman and Klatzky,, 1987). Earlier research performed on 2-month-old infants and using a bi-directional crossmodal shape transfer task (Streri 1987) revealed that two-month-old infants visually recognize an object that they have previously held, but do not manifest tactile recognition of an already-seen object. A

plausible explanation of these results on lack of bi-directional crossmodal transfer is that, as in newborns, the levels of representation attained through each modality are not sufficiently equivalent to exchange information between sensory modalities. This hypothesis seems to be validated by the fact that if a two-month-old baby is presented with degraded visual stimulation (a bi-dimensional sketch of an 3D object) in which volumetric and textural aspects are missing, leading to a blurred percept, tactile recognition is possible, which is not the case with a visual volumetric object (Streri and Molina 1993). This result means that the infant's hand cannot sufficiently explore the held object to obtain a clear representation of this object.

A number of studies have also revealed that over the course of development, the links between the haptic and the visual modalities are fragile, often not bi-directional, and representation of objects is never complete: this holds not only in infancy (Rose and Orlian 1991; Streri 2007; Streri and Pêcheux 1986), but in children (Gori *et al.* 2008) and adults (Kawashima *et al.* 2002). For example, in a behavioral and PET study on human adults, Kawashima *et al.* found that the human brain mechanisms underlying crossmodal discrimination of object size follow two different pathways depending on the temporal order in which the stimuli are presented. They found crossmodal information transfer to be less accurate with VT transfer than with TV transfer. In addition, more brain areas were activated during VT than during TV. Crossmodal transfer of information is rarely reversible, and is generally asymmetrical even when it is bi-directional. However, in adults, these asymmetries can be due to experience, learning and maturation and the characteristics of these asymmetries cannot be used directly to explain the brains of newborns. To better understand results from newborns and two-month-olds, a comparison with another property (texture) in bi-directional cross-modal transfer tasks was carried out.

3.3 Shape vs. texture

The comparison between shape and texture, amodal properties, should allow testing the hypothesis of amodal perception in newborns and to shed light on the processes involved in information-gathering by both sensory modalities. However, shape is best processed by vision, whereas texture is thought to be best detected by touch (see Bushnell and Boudreau 1998; Klatzky *et al.* 1987). According to Guest and Spence (2003), texture is "more ecologically suited" to touch than to vision. In many studies on shape (a macrogeometric property), transfer from haptics to vision has been found to be easier than transfer from vision to haptics in both children and adults (Connolly and Jones 1970; Jones and Connoly 1970; Juurmaa and Lehtinen-Railo 1988; Newham and MacKenzie 1993; cf. Hatwell 1994). In contrast, when the transfer concerns texture (a microgeometric property), for which touch is as efficient as (if not better than) vision, this asymmetry does not appear.

Sann and Streri (2007) undertook a comparison between shape and texture in bi-directional crossmodal transfer tasks. They sought to examine how information is gathered and processed by the visual and tactile modalities and, as a consequence, to shed light on the perceptual mechanisms of newborns. If the perceptual mechanisms involved in gathering information on object properties are equivalent in both modalities at birth, then reverse crossmodal transfer would be expected. In contrast, if the perceptual mechanisms differ in the two modalities, then non-reversible transfer should be found. Thirty-two newborns participated in two experiments (16 in crossmodal transfer from vision to touch, and 16 in the reverse transfer). The stimuli were one smooth cylinder and one granular cylinder (a

cylinder with pearls stuck on it). The results revealed crossmodal recognition of texture in both directions.

The findings suggest that for the property of texture, exchanges between the sensory modalities are bi-directional. Complete cross-modal transfer occurs with texture but not shape. However, this is true if only the object is volumetric and not flat, because newborns do not use the *"lateral motion"* exploratory procedure to detect differences between the textures of flat objects (Sann and Streri, 2008b). Cross-modal transfer between hands also reveals differences between shape and texture properties, and suggests that establishing representations of object shape is difficult for newborns. How should these results be explained? Human infants are particularly immature at birth, and brain maturation is protracted until adulthood. Almost no neuroimaging data is available because non-invasive techniques are difficult to apply in healthy infants. For example, newborns and young infants are often asleep (however, see Fransson et al., 2010 for a review on the functional architecture of the infant brain). Adult neuroimaging data, in contrast, offer some insights on how the brain processes cross-modal tasks.

3.4 Neuroimaging data

On the basis of these findings, two main questions emerge: First, why is bi-directional intermodal transfer observed for texture and not for shape? Second, how is haptic input translated into a visual format in newborns, i.e. by an organism that has never both seen and felt a 3D object?

On the basis of animal and human studies, Hsiao (2008) claimed that 3D shape processing involves the integration of both proprioceptive and cutaneous inputs from the hand. As the hand explores objects, different combinations of neurons are activated, and object recognition occurs as these 3D spatial views of the object are integrated. Cutaneous inputs related to 2D stimulus form and texture properties do not need such integration and may be processed differently than 3D shape in cortex. Cutaneous inputs stemming from the form and texture of 2D stimuli are processed in area 3b of SI cortex, whereas the sensitivity of neurons in area 2 to cutaneous inputs depends on hand conformation and its changes. Moreover, according to Hsiao (1998), the mechanisms underlying the early stages of 2D form processing are similar for vision and touch. Newborns' exploration of objects is very weak, and they may not be able to establish the 3D representations needed to perform tactile recognition after visual exploration of the object. Since texture and 2D form are similar in vision and touch, this data could explain why in 2-month-olds intermodal transfer from visual 2D object to haptic 3D objects is found, but not transfer from visual 3D objects to haptic 3D objects. Similarly, this data could explain the bi-directional transfer of texture between touch and vision observed in newborns.

Moreover, neuroimaging data from human adults suggests a functional separation in the cortical processing of micro- and macrogeometric cues (Roland et al. 1988). In this study, adults had to discriminate the length, shape, and roughness of objects with their right hand. Discrimination of object roughness activated lateral parietal opercular cortex significantly more than length or shape discrimination. Shape and length discrimination activated the anterior part of the intraparietal sulcus (IPA) more than roughness discrimination. More recently, Merabet *et al.* (2004) confirmed the existence of this functional separation and suggested that occipital (visual) cortex is functionally involved in tactile tasks requiring fine spatial judgments in normally sighted individuals. More specifically, a transient disruption

of visual cortical areas using rTMS (repetitive Transcranial Magnetic Stimulation) did not hinder texture judgments, but impaired subjects' ability to judge the distance between dots in a raised dot pattern. Conversely, transient disruption of somatosensory cortex impaired texture judgments, while interdot distance judgments remained intact. In short, detection of shape and texture properties requires different exploratory procedures, and takes place in two different pathways in adult brains.

A second important question is that of how haptic input is translated into a visual format given that the sensory impressions are so different and that newborns have no experience with tactile and visual object inputs. To date, there is substantial neuroimaging evidence from adults showing that vision and touch are intimately connected, although views on this interconnectedness vary (see Amedi *et al., 2001*; Sathian, 2005 for reviews). Cerebral cortical areas that were previously considered as exclusively visual, notably lateral occipital complex (LOC), are activated during haptic perception of shape (Lacey *et al.,* 2007). Crucially, LOC is activated in tactile recognition without mediation by visual recognition. Allen and Humphreys (2009) tested a patient with visual agnosia due to bilateral lesions of the ventral occipito-temporal cortex that had spared dorsal LOC. This patient's visual object recognition was impaired, but his tactile recognition was preserved. As a consequence, activation of dorsal LOC by tactile input can work directly through tactile inputs, and visual experience is unnecessary for LOC regions to be active in tactile object recognition. It seems plausible that visual imagery does not exist in newborns because they have little or no experience of the visual world of objects. It is possible that the LOC is activated in newborns brains when they explore an object haptically, and that the visual recognition of felt shape in cross-modal transfer tasks is not due to any visual imagery.

4. Conclusions

We recognize, understand, and interact with objects through both vision and touch (cf. Hatwell, Streri and Gentaz, 2003; Gentaz, 2009). In infancy, despite the various discrepancies between the haptic and visual modalities—such as asynchrony in the maturation and development of the different senses, distal vs. proximal inputs, and the contrast between the parallel character of vision and the sequential nature of the haptic modality—both systems detect regularities and irregularities when they are in contact with different objects, from birth onward. Conceivably, these two sensory systems may encode object properties such as shape and texture in similar ways. Behavioral evidence in newborns has revealed the involvement of different levels of abstraction in different types of transfer. Intermanual transfer of shape and texture seems to be bi-directional from birth. When newborns hold an object in one hand, left or right, its shape and texture are recognized by the other hand despite the immaturity of the corpus callosum. The maturity of the haptic sense is sufficient for gathering and processing information in a way that makes symmetrical correspondences between hands possible. This intermanual transfer may involve a low level of abstraction, because it does not require a change of representational format, since the steps involved, habituation and recognition, occur entirely within one modality—despite the fact that the transmission runs through the corpus callosum, which is immature at birth. Cross-modal transfers between vision and touch require a change of format and seem to be more difficult for newborns because of the higher level of abstraction involved.

Studies on crossmodal transfer tasks have revealed some links between the haptic and visual modalities at birth. Newborns are able to visually recognize a held object (Streri and

Gentaz 2003). This neonatal ability is independent of learning or the influence of the environment. However, by means of bi-directional crossmodal transfer tasks, Streri and colleagues have provided evidence on the perceptual mechanisms present at birth that constrain or limit the exchange of information between the sensory modalities. Newborns visually recognize the shape of a felt object, but are unable to recognize the shape of a seen object with their hands (Sann and Streri 2007). The link is obtained from the simplest information gathered, i.e. tactile information. Moreover, it is observed only with the newborn's right hand and not with the left (Streri and Gentaz 2004). A third striking result is that crossmodal transfer depends on object properties, being bidirectional with texture but not with shape (Sann and Streri 2007)—although this finding holds if, and only if, the felt textured object is volumetric, and not flat (Sann and Streri 2008b). For shape, just as for texture, the newborn's exploratory procedures are limited to the grasping reflex, which makes effective exploration of object properties impossible. All of these findings suggest that at birth, the links between the senses are specific to individual modalities and are not yet or entirely a general property of the brain.

Asymmetries in cross-modal transfer tasks continue to be found throughout the course of development. Several studies have also revealed that the links between the haptic and visual modalities are fragile, often not bi-directional, and representation of objects is never complete: this holds not only in infancy (Rose and Orlian 1991; Streri 2007; Streri and Pêcheux 1986b), but in children (Gori *et al.* 2008) and adults (Kawashima *et al.* 2002). Crossmodal transfer of information is rarely reversible, and is generally asymmetrical even when it is bi-directional (see Hatwell, Gentaz and Streri, 2003 for a review). The links between sensory modalities for object shape over the course of development appear to be flexible rather than immutable.

Why does cross-modal integration of spatial information develop in an asymmetrical manner? Several explanations may be offered. Sensory systems are not mature at birth, but become increasingly refined as children develop. Sometimes seen objects are observed to be well-recognized by touch, and more often, felt objects are well-recognized by vision. One possibility is that the sensory systems involved in spatial perception need to be continuously recalibrated during development, to take into account physical growth, such as changes in digit length (which affect haptic judgments), interocular separation, and eyeball length (affecting visual judgments). However, from birth, the links between the senses are more often effective when they begin with the hands rather than the eyes. Animal and adult neuroimaging studies also highlight asymmetries in cross-modal transfer tasks. Another suggestion would be that the links from eyes to hands are more effective for reaching and grasping objects than for cross-modal recognition. When we see an object, usually we take in information for some other purpose: e.g., transporting it to the mouth or somewhere else. In infancy, the hands are used as instruments to transport objects to the eyes or mouth, and the acquisition of this new ability develops to the detriment of the hands' perceptual function. Sensorimotor coordination triggered by the sight of an object is present from birth even though this ability mainly starts to be effective at about 4/5 months, at the beginning of prehension-vision. This ability may be better understood as the counterpart of cross-modal transfer from touch to vision. In both cases, perception and action are strongly linked. It is therefore important to note that sensory integration problems have often been observed in developmental disorders such as autism, dyslexia, and attention deficit disorder: understanding how incoming sensory information is transformed into outgoing motor commands is crucial for the diagnosis of such disorders (see Stein et al., 2009).

5. Acknowledgement

6. References

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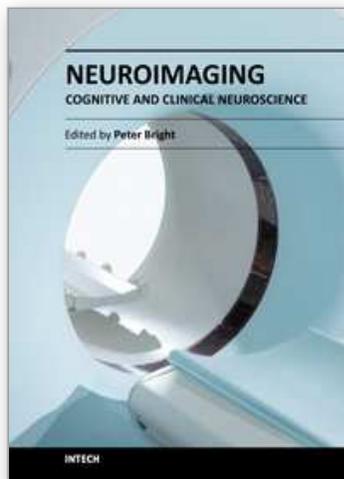
Neuroimaging - Cognitive and Clinical Neuroscience

Edited by Prof. Peter Bright

The rate of technological progress is encouraging increasingly sophisticated lines of enquiry in cognitive neuroscience and shows no sign of slowing down in the foreseeable future. Nevertheless, it is unlikely that even the strongest advocates of the cognitive neuroscience approach would maintain that advances in cognitive theory have kept in step with methods-based developments. There are several candidate reasons for the failure of neuroimaging studies to convincingly resolve many of the most important theoretical debates in the literature. For example, a significant proportion of published functional magnetic resonance imaging (fMRI) studies are not well grounded in cognitive theory, and this represents a step away from the traditional approach in experimental psychology of methodically and systematically building on (or chipping away at) existing theoretical models using tried and tested methods. Unless the experimental study design is set up within a clearly defined theoretical framework, any inferences that are drawn are unlikely to be accepted as anything other than speculative. A second, more fundamental issue is whether neuroimaging data alone can address how cognitive functions operate (far more interesting to the cognitive scientist than establishing the neuroanatomical coordinates of a given function - the where question).

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