
WHAT CAN NEUROIMAGING TELL US ABOUT THE EARLY DEVELOPMENT OF VISUAL CATEGORIES?

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ABSTRACT

While brain imaging studies of visual cognition have contributed extensively to our understanding of the different mechanisms involved in object processing and categorization, in adulthood, infancy studies have only started to employ these techniques. We identify in this paper a few of the methodological and theoretical reasons that hindered a more enthusiastic use of imaging methods. Focusing on three theoretical questions that stand out from the infant object categorization literature we show that, when the methodology is adapted to the study of young populations and the interpretations guided by equivalent results from the adult literature, brain imaging can help shed light on cognitive development.

KEYWORDS: *infants, categorization, brain imaging, ERPs, language.*

Brain imaging methods have greatly contributed to the understanding of visual cognition, in adulthood. Guided by the results obtained with more invasive methods in monkeys, human brain imaging techniques, that vary both in temporal and spatial resolution, have provided access to different dimensions of visual processing. These techniques fall into two categories, those measuring the brain electrical activity – the Electroencephalography (EEG) and the Magnetoencephalography (MEG) and those measuring the brain activity indirectly, by detecting changes in the cerebral hemodynamics – Functional Magnetic Resonance (fMRI) and recently the Near Infrared Spectroscopy (NIRS). fMRI has greatly helped to understand both the anatomical and functional organization of the visual areas in the brain. EEG and MEG have allowed us to chart the temporal unfolding of object processing in real time. More recently, with the advent of better

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localization algorithms, these electrophysiological methods have also begun to provide good spatial information about the location of neural processes, albeit with lower resolution than fMRI.

By using well-established experimental paradigms in conjunction with the above imaging techniques, it is now possible to explore a variety of brain related cognitive issues such as the selectivity of a type of process and the developmental time-course of this specialization, the effect of expertise on neural processes, and the modularity or interactivity of different types of cognitively relevant neural processes. Such questions are of major relevance for understanding cognitive development. A very rich collection of behavioural data has shown that infants' perception of their visual environment changes dramatically from the first minutes of life until adulthood. We believe that understanding these changes can be greatly helped by our knowledge of brain development.

Despite this great potential, the number of infant neuro-imaging studies is still relatively small. Numerous ethical and methodological barriers largely prevent fMRI and MEG from being employed with young healthy children. Both these methods are very sensitive to motion artefacts and thus require the immobilization of the infant's head. fMRI also involves subjecting the baby to radio frequency magnetic pulses and to high levels of noise. However, where procedural solutions that minimize infants' discomfort during MRI scanning have been found¹, valuable information was obtained in diverse domains such as the localization of language-specific areas in infants as young as three months of age (Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002) and the connectivity between different subcortical structures and cortical areas (Dubois, Hertz-Pannier, Dehaene-Lambertz, Cointepas, & Le Bihan, 2006). Moreover, with very young participants, there is the problem of trying to limit the frequent motion artefacts. However, with these disadvantages also comes a big advantage, these imaging methods do not require any explicit behavioural response from the participant. This is good news for studying early development because it sidesteps the problem of what behavioural methods to use. Indeed, because infants change so rapidly in the first 2 years of life, we are often forced to use different behavioural tasks to assess competence at different ages. However, such a practice is always open to the possibility that any developmental differences observed are simply due to task differences (e.g., visual preference versus object manipulation) used to assess competence at different ages (see also Aslin & Fiser, 2005 for a discussion of this point).

In contrast to fMRI and MEG techniques EEG-derived measures have been used for over four decades for the study of infant cognitive development.

¹ For more information on how fMRI practices have been adapted to infant studies: Stokowski, L.A., 2005. *Ensuring safety for infants undergoing Magnetic Resonance Imaging*, *Advances in Neonatal Care*, 5 (1) and on the following webpage: <http://www.unicog.org/main/pages.php?page=InfantEthics>

Most commonly used are the event related potentials (ERPs). These are electrical events evoked as a result of an external stimulation and extracted from the background EEG noise by the averaging of repeated measurements. When studying visual activity and recording the ERPs over the occipital lobe the term employed is visual evoked potentials (VEPs). Different components of the ERPs have been related to different stages of visual processing. Components like the N290 or the P400 are believed to be of cortical origin and to correspond to perceptual processing, while later slower components (e.g., negative component Nc, positive slow wave PSW) are believed to be the result of attention or memory processes (Csibra, Kushnerenko, & Grossmann, in press).

A new method, the Near-infrared spectroscopy (NIRS) has joined lately the techniques of brain investigation, in infancy. This technique is similar to fMRI in that it measures brain activity indirectly through its effects on the cerebral blood oxygenation. The promise of a better spatial resolution than that provided by EEG, coupled with fewer constraints on infant's immobility than those imposed by fMRI, explain the increasing interest in this method (Aslin & Mehler, 2005). Nonetheless, as we stand today, the few NIRS infants studies have only gone as far as showing that this method can measure visual cortex activity, for various visual stimulations (Csibra, Henty, Volein, Elwell, Tucker, Meek, et al., 2004). In case this method also shows reliable sensitivity to experimental manipulations, it has great potential for the study of functional brain development.

In the rest of this article, we will focus on a few questions with developmental relevance and for which we feel that adult brain imaging studies have made a valuable contribution. As well we will argue that only small adjustments need to be made to apply similar methods to the study of development. In particular, we will examine (1) the issue of a developmental shift from general-purpose to category specific visual object-processing, (2) evidence of a taxonomic organisation of the visual world, and (3) the link between linguistic and non-linguistic concept acquisition. In each case, we will discuss how neuroimaging (especially electroencephalography) could bring additional valuable information to light.

THE EMERGENCE OF CATEGORY-SPECIFIC VISUAL PROCESSING

The adult literature contains a very large number of studies revealing evidence of category-specific processing and its associated neural substrates. Category-specific processing can be assessed behaviourally by showing better performances for the target category than for any other, in a particular task. This approach does not help us choose between a quantitative and a qualitative difference in performance, while finding distinct neural substrates, would. Specialized neuronal substrates (or at least specialized electrophysiological markers) have been found in adults, for faces (Kanwisher, McDermott, & Chun, 1997; Rossion, Gauthier, Tarr, Despland, Bruyer, Linotte, et al., 2000) and more

generally human bodies (Gliga & Dehaene-Lambertz, 2005) as opposed to other objects. Several authors have argued that this difference stems from the fact that faces and bodies are encoded "holistically" as opposed to the piece-meal way in which other objects are encoded (Kanwisher, Tong, & Nakayama, 1998; Stekelenburg & de Gelder, 2004). Another example of category specific processing appears to exist between tools and living things. Images of tools are processed according to their functional properties whereas living things are processed according to perceptual properties (Martin, Wiggs, Ungerleider, & Haxby, 1996). In one fMRI study the perception of animals activated the middle fusiform gyrus while tools activated regions of the temporal cortex close to the movement perception area and also premotor cortex (Chao, Haxby, & Martin, 1999).

Developmentally, we still know little about when the processing of faces, living things or tools becomes category-specific. Behavioural studies have shown that acquiring face expertise is a slow process, with face recognition becoming adult-like only at adolescence (Carey, 1992). Recent fMRI studies seem to confirm that the specialization of face fusiform area parallels the behavioural trajectory, with very little face-specific activity being found in this area in young children (Passarotti, Smith, DeLano, & Huang, 2007; Scerif, Behrmann, Humphreys, & Luna, 2007). Taylor, Batty and Itier (2004) have shown that face-specific electrophysiological correlates gradually become adult-like between 4 and 15 years of age.

These results appear to contradict what might be expected given the importance of faces in early infant social interactions (Gliga & Csibra, 2007), suggesting a need to better understand the specialization of face processing in early development. Signs of earlier neural specialization were found by Halit, de Haan, and Johnson (2003). In this study inversion effects on face evoked ERPs were found to be stronger for human faces than for monkey faces by 12 months of age, suggesting that neuronal specialization for face processing starts long before we can see anatomically delimited specialization, using fMRI.

Taken together, these studies inform us about the time-course of face specialization but can brain imaging also reveal when face and object processing first dissociate? Object individualization studies provide some evidence for the differential processing of faces and other objects. In these studies the focus is on the interplay between spatio-temporal cues and surface cues in object individuation in occlusion events. Infant's knowledge is tested by measuring their reaction to events that violate the continuity of either featural or spatio-temporal properties of objects. Mareschal and Johnson (2003) showed that the kind of object used determined which type of information infants remembered during the occlusion. For faces and iconic images (stars), surface features were better remembered while for toys the spatio-temporal information was better remembered. This difference is interpreted in terms of the segregation of the two streams of visual processing (Milner & Goodale, 1995). Faces and stars are processed in the ventral stream while toys, which are graspable object (and in this sense equivalent to tools), are

processes by the dorsal stream. It would be interesting to know what other classes of objects are processed in a similar way to faces and for which, on the contrary, the affordances are more important than the surface features, and under which conditions. Thus, finding neural markers that would differentiate between these two types of object processing might be helpful.

Direct evidence for distinct neural correlates was reported by Southgate, Csibra, Kaufman, & Johnson (in press). These authors recorded EEG gamma band activity (~40 Hz) while infants watched face and toy occlusion events. An increase in gamma band power had previously been found in infants whenever an object's presence needed to be maintained in memory, such as during occlusion (Kaufman, Csibra, & Johnson, 2003, 2005). Southgate, Csibra, Kaufman, and Johnson (in press) found a similar gamma band increase when toys were occluded but not when faces were occluded. However, if the occlusion was followed by another face being revealed, this change was reflected in the gamma band activity. The same was not true for toys. This is interpreted as a neural dissociation between the nature of the information remembered for faces (featural information) versus that remembered for toys (location information).

The difference between face and object processing might stem not only from the specific need for individual recognition for faces but also from the role that faces and people in general play in infants' social interactions (Gliga & Csibra, 2007). Other brain regions, those involved in the processing of social stimuli, might specialize faster than those involved in face recognition. Recently Grossmann, Johnson, Farroni, and Csibra, (in press) measured the gamma-band oscillatory activity evoked by the perception of faces with direct and averted gaze and found that direct gaze, signalling social contact, induced a gamma burst over frontal regions, in six months olds, similarly to how the adult brain reacts in equivalent situations (Kampe, Frith, & Frith, 2003). Future studies will tell us whether this response is induced only by direct gaze or more generally, by any signal of social contact (smiling, motherese).

Thus, while the first infant studies of gamma band activity related such activity to the maintenance of absent or partial representations (Csibra, Davis, Spratling, & Johnson, 2000), more and more studies with infants and adults suggest that this phenomenon is likely to be a general marker for object processing (Busch, Herrmann, Muller, Lenz, & Gruber, 2006). One advantage of this technique over standard ERPs is that it gives access to neural activity which is not time locked to stimulus appearance (like those reflected in the ERPs), and thus potentially to a broader range of visual object processing mechanisms. We expect this technique to be used more broadly, in the near future, with infants.

Taxonomic organization of visual categories

Object properties are also accessed and organized hierarchically. When having to enumerate object properties, adults are faster to produce those that define

the basic level of classification – the most inclusive level at which category members share a common shape (i.e. dogs vs. birds); (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). More time is required for the recognition of individuals at the subordinate level (i.e. my Dalmatian), or for accessing semantic or functional properties that group together different basic categories into an overarching superordinate level (e.g., animals, tools). This hierarchy is not absolute. For some classes of objects, like faces, or other objects for which we have developed an expertise, subordinate properties are faster accessed than basic level ones (Gauthier & Tarr, 2002). While the exact border between these levels is difficult to define, it is widely accepted that, as we move from the subordinate to the superordinate level, adults rely less on “direct” visual features and more on abstract or “hidden” properties (Tanaka, Luu, Weisbrod, & Kiefer, 1999).

A few hypothesis have been put forward on how these levels of organisation develop (Mandler, 2004; Quinn & Johnson, 2000). One view is that infants start by first grouping objects into small classes, determined by common salient visual features (e.g. deer have antlers and elephants have trunks), then gradually combine these into ever broad categories as they get older and more experienced with the world (Eimas & Quinn, 1994). An alternative view states that infants begin by parsing the world into broad categories like animates and non-animates, on the basis of hidden properties, like object functions, or “essences” (Mandler & McDonough, 1998) and gradually differentiate these into more refined categories as they get older and more experienced. However, we need to be careful when interpreting infant categorisation. Indeed, we cannot assume that even if infants appear to possess a certain adult-like category distinction (e.g. animals versus vehicles) they use the same level of description and the same properties as adults do when making the same distinction (Rakison, 2000; Reznick, 2000). Even global categories such as animals and vehicles, which correspond to a superordinate distinction, from an adult perspective, might start out as perceptual categories, gradually becoming more abstract as infants encounter more and more new exemplars and learn about their properties. Some studies have shown that even 4-months-olds are able to form both basic-level as well as global-level categories (Behl-Chadha, 1996). However, it is not until 18 months that infants appear able to switch between levels of categorization (Mareschal & Tan, 2007), just as adults can.

How adults classify objects is frequently assessed verbally (Mervis & Rosch, 1981; Tanaka & Taylor, 1991). As they move from superordinate to subordinate categorization adults will list more and more detailed perceptual properties (e.g., long beak, brown). However, this approach is impossible in young pre-verbal infants. Thus, one strategy used for assessing perceptual versus conceptual categorisation in infants has been to gradually decrease the between-class perceptual dissimilarity, thereby requiring infants to base their category distinction on something other than pure perceptual properties (Pauen, 2002). Brain imaging could make a real contribution here by bridging the gap between adult and

infant category learning. For example, brain imaging could find the neural correlates of “perceptual” as opposed to “conceptual” processing in adults and then track the origins of these markers in infants. Two kinds of distinctions are expected: a spatial one, “perceptual” processing being associated with more posterior activity, over the areas involved in the first steps of visual analysis, and a temporal one, “perceptual” preceding “conceptual” analysis. Assuming that there is a correspondence between the neural mechanisms behind these types of categorization at different ages, the next step would then be to employ these markers to unveil the nature of pre-verbal infants categorization.

One of the first brain imaging studies to address the neural correlates of categorization at different levels, in adults, is that of Tanaka et al., (1999). This group measured ERPs while subjects categorized the same images of animals or tools at subordinate (e.g. claw hammer), basic (e.g. hammer) or superordinate level (e.g. tool). Categorization at the subordinate and superordinate levels was accompanied by spatially and temporally distinct neuronal responses, when compared to the basic level condition. An early posterior negativity was recorded for subordinate categorization (~ 160 ms). When the same image had to be classified as animal or tool a later difference developed, over left anterior electrodes. This dissociation between posterior and frontal regions is in concordance with the involvement of more perceptual as opposed to more semantic processes, in these two levels of categorization. A posterior negative deflection is generally induced by attention to object features, such as shape, color (Hillyard & Anlo-Vento, 1998) or by expertise with a class of objects such as card, birds, greebles (Gauthier, Curran, Curby, & Collins, 2003; Rossion, Gauthier, Goffaux, Tarr, & Crommelinck, 2002). In contrast, frontal regions are known to be involved in semantic processing (Martin & Chao, 2001).

Vuilleumier, Henson, Driver, and Dolan (2002) have used fMRI techniques to examine those regions that decreased their activity following the repetition of either the same object (with different sizes or orientations) or of physically different objects but sharing the same lexical entry (different kinds of telephones). Only the second type of repetition affected a left inferior frontal region suggesting again that frontal regions might be necessary to group together physically dissimilar items. Note also that the design of the so-called “repetition suppression” paradigms is very similar to the infant habituation technique. We will come back to this parallel and how we can make use of it in the next section.

The very brief review of the adult literature presented above gives us a few starting points for approaching the development of category learning using brain imaging tools. While the development of face processing and its neural correlates has been given a lot of attention (De Haan, Johnson, & Halit, 2007; Gauthier & Nelson, 2001), we are aware of only one study in which ERPs were used to investigate the learning of basic level categories in infants. Quinn, Westerlund and Nelson (2006) trained 6 month old infants by presenting them with 36 cat images. During the test phase 20 new images of cats were presented intermixed with 20

images of a new category (dogs). A behavioural test was administered as well, ensuring that the group of infants did show the behavioural markers of category learning. The presentation of a new category (i.e. the first sixteen cat images and the dog images) was accompanied by a negative slow wave around 1300 ms after the stimulus presentation, over the posterior left electrodes. The authors see this response as a marker of perceptual learning of a new “basic-level” category. Its posterior location is indeed consistent with that reported in adult literature, for tasks where basic or subordinate level judgements had to be made.

The comparison between the ERPs to the new category (dogs) versus the old category (new cats) was expected to reveal the neural markers of category discrimination. This comparison leads to an earlier difference, (400-500 ms) over the anterior electrodes. Similar responses, normally designated as negative component (Nc), are a general marker of attention orientation (Csibra et al., in press), triggered here probably by the appearance of the novel category. The absence of a non-ambiguous marker for basic-level category discrimination could be a consequence of the experimental design used in this study. Novel and old categories were presented with equal frequency. Oddball presentations, where the members of one class of stimuli are less frequent than the other class, are known to generate stronger discrimination responses (Näätänen, Jiang, Lavikainen, Reinikainen, & Paavilainen, 1993). The oddball stimuli are generally compared to the same stimuli presented with a 100% frequency, in a different run. The mechanism behind the oddball responses is probably similar to the “repetition suppression” fMRI paradigms discussed above (Dehaene-Lambertz & Gliga, 2004) where the repetition of a class of stimuli induces a decrease in the neuronal firing and a recovery of response when a new class of stimuli is presented (Grill-Spector & Malach, 2001; Naccache & Dehaene, 2001). The repetition-suppression is now frequently used to study the different stages of object processing, with fMRI, (Vuilleumier et al., 2002), but also using ERPs with adults (Gauthier et al., 2003) and was successful in testing infants as well (Gliga & Dehaene-Lambertz, 2007).

This paradigm is advantageous because it triggers discrimination markers without necessitating an active response from the subject, which makes it perfectly suitable for infant studies. Gliga and Dehaene-Lambertz (2007) showed that repeating images that were perceptually similar to the oddball images affected the amplitude of earlier ERPs components more than when dissimilar (but semantically related) images were presented. Repetition of different front-view faces diminished the amplitude of the eye-evoked N290 while the repetition of profile-view faces affected a later component, the P400. Thus, ERPs allowed the authors to distinguish between two types of category representations – view-dependent and view-independent, which are accessed at different time points. While this study employed faces we see no theoretical reason why the same type of paradigm would not be applicable to other types of stimuli.

We believe that even if few in number, the existing studies exploring the neural basis of category learning and perception in infancy are encouraging. They show great potential for more in-depth investigations of the theoretical issues addressed by this section. One of the first questions that future studies might ask is whether we can find in infants, as in adults, general markers for accessing basic-level/perceptual categories (e.g., cats vs. dogs) versus more global-level/conceptual categories (e.g., animals vs. vehicles). Based on the above studies, we see two roads to answering this question. Using the approach of Quinn, Westerlund and Nelson, (2006) one can measure the ERP modifications induced by learning a basic-level category (e.g., dogs) versus a more inclusive category (e.g., animals) and hope to find differences in topography. For example, can we observe a shift from posterior to more anterior electrodes as we move along the perceptual-conceptual dimension (from “cats” to “four-legged” animals to “living things”) and at which point on the gradient will this shift be observed. Thus, ERPs could bring more than just a success or failure-to-categorize answer, they could also tell us at which level the categorization is done and how this changes with the development.

The temporal unfolding of categorization can be investigated by using a repetition paradigm in which the relationship between the oddball stimuli and the context stimuli spans the perceptual-conceptual dimension. In adults basic-level access seems to precede super-ordinate level access (Tanaka et al., 1999), while in infants the opposite is postulated, at least for category learning (Quinn et al., 2006), based on neural-network simulation data (Quinn & Johnson, 2000). This would be explained by infants first focussing on those features that are common to all global category members (e.g., legs) and then on distinctive features (e.g., trunk vs. antlers). This paradigm allows us to ask in infants a similar question as that asked by Tanaka et al. in adulthood, without necessitating any overt response from the targeted population.

LANGUAGE AND CATEGORIZATION

Infants start acquiring their first words at the end of their first year of life. By their first birthday they already comprehend about 70 words (Fenson, Dale, Reznick, Bates, Thall, & Pethick, 1994). A number of studies have now shown that learning words and category learning do not develop independently of each other. Waxman and her colleagues showed that consistent labelling of different objects helps infants incorporate these objects into a single category. The additional effect of labelling is stronger when the exemplars vary perceptually (Waxman & Braun, 2005; Waxman & Markow, 1995). Similar facilitating effects are found when adults learn novel categories (Lupyan, Rakison, & McClelland, in press). The specificity of these effects was challenged by subsequent studies which showed that not only words but any accompanying consistent auditory stimulus has the same effect on category learning, at least in infancy (Sloutsky & Napolitano,

2003). It is thus unclear whether words have a special status in category learning, or not, in infancy.

In the previous sections we discussed the neural correlates of categorization at different hierarchical levels. Apart from the antero-posterior differences, an additional effect warrants attention. In all these studies the left hemisphere seemed to be more invariant than the right to modifications which affect the appearance of an object but not its basic level entry, like those induced by object rotation or by varying the category exemplar presented (Koutstaal, Wagner, Rotte, Maril, Buckner, & Schacter, 2001; Marsolek, 1999; Simons, Koutstaal, Prince, Wagner, & Schacter, 2003; Vuilleumier, Henson, Driver, & Dolan, 2002). A recent MEG study claims to have found a left hemisphere clustering of areas processing different objects from the same superordinate category (Low, Bentin, Rockstroh, Silberman, Gomolla, Cohen, et al., 2003). The left hemisphere is believed to be more “abstract” while the right hemisphere would be more involved in detailed perceptual analysis.

The parallel between the left hemisphere encoding of more abstract categories and the language lateralization is striking. The link between objects and labels is additionally reinforced by the fact that word to picture priming activates left-lateralized regions (Simons et al., 2003). It is therefore possible that language, in the form of word learning for example, constrains the acquisition and the cerebral location of category representations. It has been shown that when learning abstract categories adults start by activating the right hemisphere but, in those participants who best succeed in the task, this right activations are accompanied late in the task by left dorsolateral prefrontal cortex activation (Seger, Poldrack, Prabhakaran, Zhao, Glover, & Gabrielli, 2000). These same participants state that they end by using linguistic strategies to remember the category distinctions.

Do we see any evidence for language effects on the category representations in the developmental neuroscience literature? Quinn et al. (2006) study does find left-lateralized responses for basic-level category learning. This suggests that language is not necessary for the left-lateralization of category representations, because the category was learned in this study based only on visual information and because we do not expect 6-month-olds to have been familiar with the meaning of words “cat” or “dog”, before coming onto the lab. However, this alone does not completely undermine the possibility that language does modulate the relative role of the two hemispheres in category learning. While the above comments are still speculative we hope future brain imaging studies will clarify this issue by comparing laterality effects when category learning is accompanied by labelling, by non-linguistic auditory stimuli or by none of them.

CHOOSING THE RIGHT METHOD FOR EACH DEVELOPMENTAL QUESTION

We started this manuscript with the purpose of highlighting how brain imaging can complement behavioural measures, when exploring the development of visual category learning. We focused on three questions where we believe a neuroscientific approach can enrich our knowledge and where adult research is advanced enough to provide the necessary background. We therefore hope to have encouraged more researchers to step on to this methodological path.

It is nevertheless understandable that the long tradition of behavioural methods and the technical and sometimes financial challenge of brain imaging methods might make a lot of us cautious in taking such a big step. A few questions deserve to be asked before hand: Is brain imaging always more informative than behaviour? What if the behavioural and the neuronal results conflict, which one should we believe? Can we always assume the equivalence between neural markers in infants and in adults?

The ultimate goal of all infant studies presented in this manuscript is to understand infant cognition, i.e. why infants behave the way they do and when they do it. From this perspective behavioural measures seem to be closer to the level we are interested in, to the *output*. But are they? In some cases we are confident in giving a positive answer to this question. Preference measures tell us not only that infants see a difference between two images but also that they would spend more time scanning one of them, which consequently might affect subsequent processes like recognition or categorization. Even with this method there are additional issues with interpreting the direction of infant's preferences (either familiarity or novelty preference), which should be further investigated. If we are only interested in whether infants can discriminate between stimuli we might employ a habituation paradigm. Here a sequence of exemplars from one category is presented at a time to the baby until she decreases her looking time. At this point an image from a contrasting category is presented and the looking time is expected to recover. Such a scenario and the subsequent behaviour are unlikely to occur in real life. Thus, apart from showing discrimination, this measure tells little about how infants sample the visual information and thus about the underlying mechanisms of naturalistic category learning. In this case electrophysiological measures could provide equivalent information and, as we have seen previously, even additional information. More than just giving a Yes-No answer, they can tell us whether infants employ different processing strategies (as is the case of using perceptual or conceptual properties for categorization) or direct our hypotheses about the underlying nature of these strategies (as in the case of the parallel between the left lateralization of some category representations and of language).

What if we decide to use both type of measures and the results contradict each other: we find no dishabituation to a novel category while ERPs do measure a difference between the old and new categories? Does the behavioural result nullify the electrophysiological one? The contrary case can occur as well, we could have

positive behavioural results but no effect on the brain activity. Null results are, as always, difficult to interpret. The absence of a behavioural effect might be the result of not enough sensitivity. Null results in brain imaging can originate for various reasons, which do not have to be functional (e.g. the depth or size of the targeted neuronal structures, the folding of the cortical surface). A more problematic case is that in which both methods produce positive results but which contradict. One such example is given by studies of visual acuity thresholds. Sokol & Moskowitz, (1985) measured a lower threshold with VEP than with preferential looking, in 3-month-olds. As we have seen visual processing goes through steps in which different types of representations are being calculated subsequently, only the last ones influencing the behavioural outcome. If only the earlier levels are “visible” for brain imaging, this could lead to the above discordances with the behavioural measures. Slight differences between the paradigms used for behavioural and brain-imaging studies may as well be a cause of inconsistent results. We do expect though that such cases would be more the exception than the rule.

A last aspect to address is that of the equivalence between infant and adult neural markers. We based some of our suggestions for future directions in the study of visual development on the assumption that the same markers could be found at different ages. If topography, polarity and latency of the ERP waves are similar across the ages it is reasonable to assume homologies in the underlying mechanisms (Friederici, 2005). Even when differences are encountered it is still possible that they correspond to anatomo-functional modifications accompanying the development of the brain and not to functional differences. This issue could be clarified by looking at how these components change along the development, from infancy to the adult state. One classic example is the parallel drawn between the adult face specific N170 and the infant N290. Both these components are negative deflections over the occipital electrodes but the N170 is stronger over the lateral electrodes while the N290 is more medial. A continuous change was observed between 4 years of age, when recording the face-evoked posterior ERPs, suggesting that despite the initial topographical differences, the N290 might be functionally equivalent to the adult N170 (Taylor et al., 2004).

CONCLUSION

The advance of both our understanding of the neural correlates of object processing in adults and of infant-friendly brain imaging techniques are an incentive to use these techniques for the study of cognitive development. The development of category-selective processing, that of category taxonomies or the interplay between language and categorization are only a few examples where brain imaging could have a contribution. While we are aware that this will only happen if some of the predictions that we made turn out to be true (e.g. finding neural correlates of perceptual and conceptual processing in infancy) we hope to

have provided evidence that the two extra-dimensions, temporal and spatial (anatomical localization) gained by using brain imaging techniques, can answer additional questions to those addressed by behavioural measures.

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