Neuropsychologia 47 (2009) 2537–2543

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

IQ, fetal testosterone and individual variability in children's functional lateralization

Evelyne Mercure[a,b,*], Emma Ashwin[c], Frederic Dick[a], Hanife Halit[a], Bonnie Auyeung[c], Simon Baron-Cohen[c], Mark H. Johnson[a]

[a] Centre for Brain and Cognitive Development, Birkbeck, University of London, United Kingdom
[b] Institute of Psychiatry, King's College London, United Kingdom
[c] Department of Psychiatry, Autism Research Centre, University of Cambridge, United Kingdom

ARTICLE INFO

Article history:
Received 9 July 2008
Received in revised form 21 April 2009
Accepted 28 April 2009
Available online 5 May 2009

Keywords:
Event-related potentials
N170
Reading
Words
Faces
Development

ABSTRACT

Previous event-related potential (ERP) studies have revealed that faces and words show a robust difference in the lateralization of their N170. The present study investigated the development of this differential lateralization in school-age boys. We assessed the potential role of fetal testosterone (FT) level as a factor biasing the prenatal development of lateralization, and the role of reading skill and Verbal IQ as factors predicting left lateralization for words in childhood. The adult pattern of differential N170 lateralization for faces and words was not present in a group of 26 school-age boys. This suggests that N170 lateralization only appears with years of experience with these stimulus categories or with late childhood maturation. FT level measured by amniocentesis did not account for a significant part of the individual variability in lateralization. Verbal IQ correlated with the degree of left lateralization of the N170 to words, but this effect was not specific to language abilities and language lateralization. A strong correlation was observed between the degree of left lateralization for words and the degree of left lateralization for faces, and both lateralization scores correlated with Verbal and Performance IQ. Possible explanations for these results are discussed along with ERP correlates of words and faces in school-age boys.

In order to understand the mechanisms that lead to the functional specialization of brain areas, and to what extent this pattern is pre-determined, researchers have been studying whether lateralization of cognitive functions is present from birth. Some studies have provided evidence that functional lateralization is present to a certain degree several months after birth (de Haan & Nelson, 1999; de Schonen & Mathivet, 1990; Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002; Entus, 1977; Friederici, 2006; Tzourio-Mazoyer et al., 2002), suggesting that prenatal factors could bias each hemisphere to specialize for certain cognitive functions. However, the study of patients with early unilateral brain lesions (Bates & Roe, 2001; Dick, Wulfeck, Krupa-Kwiatkowski, & Bates, 2004), as well as electrophysiology and functional imaging studies with infants and children (de Haan, Pascalis, & Johnson, 2002; Halit, 2002; Maurer, Brandeis, & McCandliss, 2005; Maurer, Brem, Bucher, & Brandeis, 2005; Maurer et al., 2006; Mills et al., 2004; Pugh, Sandak, Frost, Moore, & Mencl, 2005; Schlaggar et al., 2002; Taylor, Batty, & Itier, 2004) suggest that lateralization evolves during infancy and childhood to eventually achieve the adult pattern. The present study investigated the factors that contribute to this development of functional lateralization for faces and for words. It had two aims: (1) to assess the potential role of fetal testosterone (FT) as a factor biasing the development of lateralization prenatally and (2) to assess the potential role of reading skill and Verbal IQ as factors predicting left lateralization for words in childhood.

In this study, functional lateralization was measured using event-related potentials (ERPs). Previous studies have shown that the N170 ERP component differs in lateralization for words and faces (Joyce & Rossion, 2005; Mercure, Dick, Halit, Kaufman, & Johnson, 2008; Rossion, Joyce, Cottrell, & Tarr, 2003), with a larger amplitude in the left than right hemisphere for words (Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999; Brem et al., 2005; Joyce & Rossion, 2005; Maurer, Brandeis, et al., 2005; Maurer, Zevin, Hulse, & McCandliss, 2007; Rossion et al., 2003; Wong, Gauthier, Woroch, DeBuse, & Curran, 2005) and a tendency for a larger amplitude in the right than left hemisphere for faces (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Bentin & Deouell, 2000; Bentin, Golland, Flevaris, Robertson, & Moscovitch, 2006; Boutsen, Humphreys, Praamstra, & Warbrick, 2006; Caldara, Rossion, Bovet, & Hauert, 2004; de Haan et al., 2002; Rossion et al., 2003). This measure was chosen as an index of functional lateralization since it has been replicated many times in adults and because it shows

* Corresponding author at: Birkbeck School of Psychology, The Henry Wellcome Building, London WC1E 7HX, United Kingdom. Tel.: +44 2070790756; fax: +44 2076316587.
E-mail address: e.mercure@psychology.bbk.ac.uk (E. Mercure).

0028-3932/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.neuropsychologia.2009.04.027

individual variability. Based on previous studies (Maurer, Brem, et al., 2005; Maurer et al., 2006; Taylor et al., 2004), this variability was expected to be even greater in children, possibly reducing the differential lateralization between categories to non-significance at the group level.

1. Fetal testosterone (FT) as a prenatal factor biasing lateralization

An influence of FT on brain lateralization was initially proposed in the early 1980s (Geschwind & Behan, 1982, 1984). The Geschwind–Behan–Galaburda (GBG) model suggested that the level of prenatal testosterone influences the rate of neuronal migration from the neural crest into the cortex, especially in the left hemisphere. A high level of FT would lead to retardation in the growth of the left hemisphere, and possibly left hemisphere abnormalities. This would prevent the establishment of left lateralization of cognitive functions and affect the development of language. Elevated FT would also have a suppressive effect on the thymus, affecting the maturation of the immune system and increasing the incidence of various immune diseases. The GBG model has been criticized because many of the predicted statistical associations were not reliably observed (Berenbaum & Denburg, 1995; Bryden, McManus, & Bulman-Fleming, 1994; Forget & Cohen, 1994; Obrzut, 1994; Previc, 1994). The evaluation of each of these associations is beyond the scope of this paper and only the predicted association between high prenatal testosterone and 'anomalous dominance' will be discussed. An alternative theory linking FT and lateralization is the callosal hypothesis, which states that brain lateralization results from the pruning of cells in the corpus callosum during the fetal and neonatal period, and that this process is influenced by testosterone levels during this period (Witelson & Nowakowski, 1991). This theory suggests that high levels of FT increase the pruning of callosal cells, which in turn decreases the connectivity between the hemispheres, and increases lateralization of brain functions. This hypothesis emerged from the author's observation that left-handed and ambidextrous individuals have a larger corpus callosum compared to right-handed individuals (Witelson, 1985).

The literature that empirically tests these models is highly variable, with evidence consistent with both the GBG model (Kelso, Nicholls, Warne, & Zacharin, 2000), and the callosal hypothesis (Cohen-Bendahan, Buitelaar, van Goozen, & Cohen-Kettenis, 2004; Grimshaw, Bryden, & Finegan, 1995) as well as evidence showing no support for an influence of FT on lateralization (Helleday, Siwers, Ritzen, & Hugdahl, 1994; Mathews et al., 2004). Since the testosterone level in the fetal blood cannot be directly accessed in humans, research teams have developed various methods of estimating this value and its impact on brain development. For example, some have studied genetic disorders associated with a high level of FT (Helleday et al., 1994; Kelso et al., 2000; Mathews et al., 2004), or studied female fetuses developing in the proximity of a male twin (Cohen-Bendahan et al., 2004). In addition, the concept of lateralization itself differs from one author to another and methods for measuring lateralization are extremely varied. Indeed, one major criticism of the GBG model is that the authors did not precisely define the term 'anomalous dominance', which in the theoretical model seemed to correspond to the organization of language in the hemispheres. However, many studies used handedness as the indicator of dominance when testing the model, despite the fact that only a modest association is found between these two variables (Bryden et al., 1994). What the literature lacks is a comparison between a prenatal measure of testosterone level and lateralization for cognitive functions assessed by a measure of brain activity.

In the present study, FT level was assessed by amniocentesis since this method is the most direct way of measuring hormonal levels in the fetal period (Cohen-Bendahan, van de Beek, & Berenbaum, 2005; Finegan, Bartleman, & Wong, 1989). Amniocentesis is a routine medical procedure used for prenatal diagnosis, whereby a long syringe guided by ultrasound is inserted through the mother's abdominal wall to extract a small amount of amniotic fluid. The level of testosterone in the amniotic fluid is uncorrelated with maternal levels of circulating testosterone (van de Beek, Thijssen, Cohen-Kettenis, van Goozen, & Buitelaar, 2004) and is believed to reflect the true level of fetal exposure (Baron-Cohen, Lutchmaya, & Knickmeyer, 2004; Finegan et al., 1989). The children who participated in the present study were recruited from a larger cohort followed longitudinally (Baron-Cohen et al., 2004). In this cohort, FT level has been found to predict several aspects of development, such as frequency of eye contact between infants and their parents at 12 months (Lutchmaya, Baron-Cohen, & Raggat, 2002a), vocabulary size at 18 and 24 months (Lutchmaya, Baron-Cohen, & Raggat, 2002b), and quality of social relationships and restrictive interests at 4 years (Knickmeyer, Baron-Cohen, Raggat, & Taylor, 2005). Only boys participated in the present study as the literature suggests that the influence of testosterone on behavior may differ in males and females, with more consistent influences observed in boys than girls (Knickmeyer et al., 2005; Knickmeyer, Baron-Cohen, Raggat, Taylor, & Hackett, 2006; Lutchmaya et al., 2002a). Boys also show greater variability in their FT level, which increases the potential sensitivity of the study. The first aim of this study was to investigate whether FT level accounts for a significant amount of the individual variability in lateralization of the N170 to words and faces.

2. Reading skill and Verbal IQ as factors predicting left lateralization for words

As mentioned earlier, there is consistent evidence to support the idea that lateralization continues to develop late into childhood, but the mechanisms underlying the establishment of this pattern are unclear. One possibility is that lateralization is reinforced as skill or expertise develops for one domain. Functional imaging studies in typically developing children have shown a correlation between reading skill and activity in the occipitotemporal region of the left hemisphere, while several right hemisphere areas showed an age- or skill-related decrease in activity (Pugh et al., 2005). Moreover, children with reading disorders usually show less activity in the left occipitotemporal region, with increased activity in its right hemisphere homologue (Pugh et al., 2005). In ERPs, skilled adult reading is reflected by the functional specialization of the N170 component, which is larger for words than for perceptually equivalent symbol strings, and left lateralized at the group level (Bentin et al., 1999; Brem et al., 2005; Joyce & Rossion, 2005; Maurer, Brandeis, et al., 2005; Maurer et al., 2007; Rossion et al., 2003; Wong et al., 2005). In kindergarten children who could not yet read, it was observed that the N170 did not differ between words and symbols and was not lateralized (Maurer, Brem, et al., 2005). After these children learned basic reading skills (in 2nd grade), the N170 was larger for words than for symbol strings, but was not lateralized at the group level (Maurer et al., 2006). Even if left functional lateralization was previously observed in infants and children performing different language tasks (Balsamo, Xu, & Gaillard, 2006; Dehaene-Lambertz et al., 2002; Friederici, 2006), these results suggest that left lateralization of the N170 for written words appears with years of experience with reading and possibly relates to reading skill. In face processing, right lateralization of the N170 is not consistently found at the group level before 12–13 years old (Taylor et al., 2004), although it is not yet clear what factors influence the establishment of this pattern.

The second aim of this study was to investigate whether a significant amount of the individual variability in lateralization of the N170 for words could be accounted for by reading skills (assessed by