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Hemispheric speech lateralisation in the developing brain is related to motor praxis ability

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ABSTRACT

Commonly displayed functional asymmetries such as hand dominance and hemispheric speech lateralisation are well researched in adults. However there is debate about when such functions become lateralised in the typically developing brain. This study examined whether patterns of speech laterality and hand dominance were related and whether they varied with age in typically developing children. 148 children aged 3–10 years performed an electronic pegboard task to determine hand dominance; a subset of 38 of these children also underwent functional Transcranial Doppler (fTCD) imaging to derive a lateralisation index (LI) for hemispheric activation during speech production using an animation description paradigm. There was no main effect of age in the speech laterality scores, however, younger children showed a greater difference in performance between their hands on the motor task. Furthermore, this between-hand performance difference significantly interacted with direction of speech laterality, with a smaller between-hand difference relating to increased left hemisphere activation. This data shows that both handedness and speech lateralisation appear relatively determined by age 3, but that atypical cerebral lateralisation is linked to greater performance differences in hand skill, irrespective of age. Results are discussed in terms of the common neural systems underpinning handedness and speech lateralisation.

1. Introduction

Functional asymmetries in hand skill and hemispheric speech lateralisation are well researched in adults. However, there is debate about when such functions become lateralised in the typically developing brain. The majority of adults demonstrate a typical pattern of right handedness and left hemispheric dominance for speech production (e.g. Knecht et al., 2000), but evidence for the neural development of motor skill and speech is more varied. Studies of language lateralisation in children show that speech is clearly lateralised to the left hemisphere at around 6 or 7 years of age (Groen et al., 2012; Gaillard et al., 2003) and evidence from neuroimaging of pre-verbal infants demonstrates an early left hemisphere dominance for processing of speech sounds (Dehaene-Lambertz et al., 2002). However it has also been suggested that younger children exhibit more bi-lateral activation during speech production compared to adults (e.g. Holland et al., 2001). Similarly, research has suggested hand preference in adulthood may be predicted from lateralized motor behaviour in early gestation, comparing ultrasound observation of thumb sucking (Hepper et al., 1991), and neonate palmar grasp reflex strength (Tan and Tan, 1999). However, varying observations of hand preference in early childhood reveal that no general consensus exists for when adult-like handedness occurs. Some studies indicate that direction of hand preference is attained by age 3 (e.g. Archer et al., 1988; McManus et al., 1988), with others reporting shifting hand usage and increased variability on manual tasks up until age 6, suggesting this is a more likely reflection of later handedness (Bryden et al., 2000).

There is evidence that task proficiency is related to increased laterality (Groen et al., 2012; Sheehan and Mills, 2008), suggesting that very young children, who are not yet competent in either speech or motor control, may display more varied patterns of hemispheric lateralisation for these functions. Current thinking proposes that whilst the direction of cerebral lateralisation for language and motor functions may be genetically predisposed, it is

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in fact a complex interaction of environmental and genetic factors which mediate the individual profile of cerebral lateralisation during development (e.g. Bishop, 2013). Therefore it is crucial to understand the extent to which an individual's laterality profile changes through development. If lateralisation shifts with age and task proficiency then it suggests that the underlying functional and structural neural architecture may also be changing and shifting in this period and is therefore potentially vulnerable to factors affecting this developmental trajectory.

Few studies have examined speech lateralisation in children below age 6, predominately due to methodological difficulties in measuring language performance in pre-verbal children. Speech paradigms designed for adults tend not to produce a reliable enough stream of speech in children, either due to task difficulty, the requirement for literacy or complex instructions not easily understood, especially by very young children. However, notable recent exceptions have been able to demonstrate that typically developing 4 year old children show predominately left hemisphere lateralised speech (Bishop et al., 2014), and that no age effects in overall laterality profile could be found in preschool children aged between 1 and 5 years (Kohler et al., 2015). That study did however find an effect of age in variability of the lateralisation measurement, which became more reliable with age. An emerging methodology known as functional transcranial Doppler (fTCD) ultrasound has been shown to be effective in overcoming the issue of problematic measurement in children, as it is non-invasive and can be performed in relative comfort, unlike other neuro-imaging techniques. Furthermore, specific speech production paradigms have been developed which allow assessment of lateralisation in pre-literate children, and which have been validated against standard word generation paradigms used in adult language lateralisation research (e.g. Bishop et al., 2009).

Research into the use of handedness as an indirect measure for speech laterality has formerly proved weak and inconclusive (Groen et al., 2013), predominately due to the variability of methodologies, and hand preference and skill definitions being highly dependent on the measurement and classification used (Groen et al., 2013). However, speech and motor control are said to share a common developmental trajectory (Iverson, 2010), sub served by overlapping neural pathways predominantly situated in the left hemisphere (see Binkofski and Buccino, 2004). Converging evidence underlines the relationship between language and motor function. For example, it has been shown that brain regions typically associated with movement (pre-motor cortex, supplementary motor area and cerebellum) are also activated by language tasks (e.g. Tremblay and Gracco, 2009; Petersen et al., 1989) and that classic speech production areas (i.e. Broca's area/Brodmann areas 44 and 45) show increased activation during the execution of sequenced hand movements (Erhard et al., 1996). In addition, individuals with aphasia (Pedelty, 1987) and children with specific language impairments (Hill, 2001) frequently display co-occurring motor deficits.

Flowers and Hudson (2013) propose that motor and speech laterality are related where they involve a common feature of motor output, namely the co-ordination of sequences of movements or utterances to execute a plan or intention so as to achieve a goal, either limb movement or expression of an idea (Grimme et al., 2011). This rationale has demonstrated that measures of performance based hand skill are better at revealing the underlying commonalities between the two functions, and thus are more effective at informing on their neurological relationship (Flowers and Hudson, 2013; Groen et al., 2013). The present study investigated the speech and motor lateralisation profiles of children aged 3–10 years to determine whether the two functions develop in parallel and, specifically, whether younger children would show more variable laterality across these functions. It focussed on a direct measure of language lateralisation (fTCD) and a handedness task (electronic pegboard) which relies on the same concept of motor sequencing suggested to underlie speech and motor action. Specifically the research questions posed were as follows: 1. does age affect motor skill performance on the pegboard task? 2. Do speech lateralisation profiles vary with age? 3. Can skilled motor performance predict direction of hemispheric speech laterality?

2. Method and materials

2.1. Participants

Participants were 153 children aged between 3yrs and 10yrs (74 males; mean age = 5.9yrs, SD age = 2.02yrs). All children were reported by parental report to be typically developing. Parents were asked to report any reading, language or motor impairments or concerns, as well as any developmental disorders such as Autism or ADHD; any children with such conditions were excluded. All participating children had normal, or corrected to normal, vision and none had a history of neurological injury or disease or were on medication known to affect the central nervous system, or cardiovascular system. All participants were British and had English as a first and only language; 4 of the 153 children tested were of African ethnicity, and the remaining 149 children were Caucasian, which is representative of the local population. Participants were recruited through local schools, parent/toddler groups and via the University of Lincoln's science outreach events. The investigation was approved by the ethics committee of the School of Psychology, University of Lincoln. Parental consent was obtained in writing at least 48 h prior to the testing session following acknowledge receipt of detailed study information sheets and briefing on the study via phone/email contact. Children were also required to assent to participation at the time of testing. Failure on behalf of the child to assent super ceded the parental consent, such that those children did not continue with the study. During testing participants were accompanied by a female experimenter sitting beside them to ensure they were happy to continue. Children were free to withdraw at any time without prejudice, and this right was clearly explained to them and they were asked to practise saying they wanted to stop. In addition, silence, lack of response, changes in demeanour and eye contact, were all taken as signs from the child of disinclination to continue, thus triggering the cessation of testing. Only one instance occurred of a child asking to withdraw before the testing had started.

2.2. Behavioural assessments

Participants completed a series of assessments to ascertain their levels of motor and language abilities.

2.2.1. Handedness assessment

All participants underwent assessments of their hand preference via completion of 5 manual tasks selected as reliable indicators of manual preference. The tasks were selected from a group of manual actions usually found on handedness questionnaires (e.g Flowers and Hudson, 2013; Annett, 2002). This approach was taken due to the range of ages in the sample, where it was considered a standard handedness inventory would be inappropriate due to the literacy skills required to complete such a questionnaire. Similarly reliance on self-reported writing hand was not considered a robust enough approach given the age range of the youngest participants.

The 5 manual tasks used to assess hand preference were as follows: 1. Underarm throw of a soft ball to the experimenter; 2. Eat with a spoon from a bowl of imaginary cereal; 3. Sharpen a pencil; 4. Unscrew a lid from a jar; 5. Draw a circle with a pencil. Each task was performed 3 times by the child and the hand used was recorded