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Face and location processing in children with early unilateral brain injury

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ABSTRACT

Human visuospatial functions are commonly divided into those dependent on the ventral visual stream (ventral occipitotemporal regions), which allows for processing the 'what' of an object, and the dorsal visual stream (dorsal occipitoparietal regions), which allows for processing 'where' an object is in space. Information about the development of each of the two streams has been accumulating, but very little is known about the effects of injury, particularly very early injury, on this developmental process. Using a set of computerized dorsal and ventral stream tasks matched for stimuli, required response, and difficulty (for typically-developing individuals), we sought to compare the differential effects of injury to the two systems by examining performance in individuals with perinatal brain injury (PBI), who present with selective deficits in visuospatial processing from a young age. Thirty participants (mean = 15.1 years) with early unilateral brain injury (15 right hemisphere PBI, 15 left hemisphere PBI) and 16 matched controls participated. On our tasks children with PBI performed more poorly than controls (lower accuracy and longer response times), and this was particularly prominent for the ventral stream task. Lateralization of PBI was also a factor, as the dorsal stream task did not seem to be associated with lateralized deficits, with both PBI groups showing only subtle decrements in performance, while the ventral stream task elicited deficits from RPBI children that do not appear to improve with age. Our findings suggest that early injury results in lesion-specific visuospatial deficits that persist into adolescence. Further, as the stimuli used in our ventral stream task were faces, our findings are consistent with what is known about the neural systems for face processing, namely, that they are established relatively early, follow a comparatively rapid developmental trajectory (conferring a vulnerability to early insult), and are biased toward the right hemisphere.

1. Introduction

Visual input is a rich and diverse source of knowledge about the spatial world. It provides information about everything from the structure of objects and scenes to their location or movement in space. Children with perinatal brain injury (PBI) exhibit deficits of visuospatial processing from very early in life, and while there is evidence for developmental improvement across the period of childhood and early adolescence, subtle deficits in visuospatial processing persist at least through adolescence (Akshoomoff, Feroleto, Doyle, & Stiles, 2002; de Schonen, Mancini, Camps, Maes, & Laurent, 2005; Reilly, Levine, Nass, & Stiles, 2008; Stiles,

Abbreviations: PBI, perinatal brain injury; RPBI, right hemisphere perinatal brain injury; LPBI, left hemisphere perinatal brain injury; TD, typically-developing; WISC-IV, Wechsler Intelligence Scale for Children—Fourth Edition; WISC–III, Wechsler Intelligence Scale for Children—Third Edition; WISC-R, Wechsler Intelligence Scale for Children—Revised; WPPSI-R, Wechsler Preschool and Primary Scale of Intelligence—Revised; WASI, Wechsler Abbreviated Intelligence Scale; VIQ, verbal IQ; RT, response time; SD, standard deviation.

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Nass, Levine, Moses, & Reilly, 2009; Stiles, Paul, & Hesselink, 2006; Stiles, Reilly, Levine, Trauner, & Nass, 2012; Stiles, Reilly, Paul, & Moses, 2005; Stiles et al., 2008).

Much of the work examining visuospatial deficits following perinatal injury has focused on processes associated with the ventral visual stream, specifically visual object and pattern processing (Ungerleider, 1995; Ungerleider & Mishkin, 1982). The ventral visual stream, which is often referred to as the "what" pathway, begins in primary visual cortex and projects through ventral temporal brain regions. Injury to these brain regions results in deficits of visual pattern and scene processing in both adult and child populations. Further, across ages, the specific type of deficit differs by laterality of injury, with deficits of either configural or featural processing associated with right or left hemisphere injury, respectively (Ivry & Robertson, 1998; Robertson & Delis, 1986; Robertson, Lamb, & Knight, 1988; Swindell, Holland, Fromm, & Greenhouse, 1988). A much smaller body of work has focused on processes associated with the dorsal visual stream, specifically location processing and mental rotation. The dorsal visual stream, which is often referred to as the "where" or "how" pathway, begins in primary visual cortex and projects through dorsal parietal brain regions (Goodale & Milner, 1992; Goodale & Westwood, 2004; Milner & Goodale, 1995; Rizzolatti & Matelli, 2003; Ungerleider, 1995). Injury to these brain regions results in deficits of spatial attention, location processing and mental rotation in both adult and child populations. Evidence for laterality effects in dorsal stream processing are limited.

Although a number of studies have examined the effects of injury to ventral or dorsal stream functions, separately, work comparing the differential effects of injury to the two systems is more limited. Within the literature on typically developing children, data on the developmental trajectories of these two systems is also limited, and in some cases contradictory. Studies focused on the early development of visuospatial processes in infants younger than a year suggest that dorsal stream functions involved in motion and location processing emerge earlier than ventral stream functions involved in feature processing (Armstrong, Neville, Hillyard, & Mitchell, 2002; Krojgaard, 2007; Mitchell & Neville, 2004; Van de Walle, Carey, & Prevor, 2000; Wilcox & Baillargeon, 1998; Xu, Carey, & Quint, 2004). By contrast, studies of older children suggest that the ventral stream processes may reach adult levels of functioning earlier than the dorsal stream (Armstrong et al., 2002; Atkinson et al., 2005; Braddick, Atkinson, & Wattam-Bell, 2003; Mitchell & Neville, 2004). Together these findings suggest a pattern of protracted development for both systems, with differential and varying rates of change for each. Specifically, dorsal system processes emerge early and undergo very protracted change that extends well into adolescence, while ventral system processes begin to emerge later in infancy but undergo somewhat more rapid development through the school-age period.

The rate of development of the two systems may impact the developmental outcomes among children with perinatal brain injury. On the one hand, early emerging systems may exhibit more limited plasticity and adaptability than later emerging systems, in which case greater compromise of dorsal stream processes would be expected. Alternatively, given that they develop more rapidly over time, greater compromise of ventral stream processes may be observed. Finally, a third possibility remains that differences in developmental trajectories may lead to differential vulnerability of each system, resulting in subtle but comparable compromise of both systems. However, there is very little data to date examining possible differences in the magnitude or distribution of the effects of injury on these two neural systems and the functions they support. While a number of studies have examined dorsal and ventral stream functioning separately, few have directly compared the two systems within the same paradigm, for example, using tasks that were matched and balanced for task demands.

The current study makes use of well-matched dorsal and ventral stream processing tasks, for which performance was equated among adults (see Appendix A), in order to examine the effects of perinatal brain injury on the development of dorsal and ventral stream processing. The study had several goals. The first was to examine possible differences in the type and magnitude of deficit observed for the two visual streams among school-age children and adolescents with perinatal brain injury analyzed as a group, that is, without regard to the question of lesion laterality. Thus, the first question addressed in this study is whether and how early injury, per se, affects the development of these two important aspects of visuospatial processing. The second goal was to ask whether laterality of lesion, right or left, is associated with differences in the type or magnitude of visuospatial processing deficit. Finally, the study considered the effects of age on task performance for children with perinatal brain injury (PBI), thus allowing us to compare trajectories of change in task performance for the PBI groups and for typically developing children.

2. Material and methods

2.1. Participants

Participants included 30 individuals with perinatal brain injury (15 with right hemisphere perinatal lesions, RPBI; 15 with left hemisphere perinatal lesions, LPBI) and 16 typically developing (TD) participants (Table 1). The PBI participants (LPBI, M = 15.2 years, SD = 4.3; RPBI, M = 15.0 years, SD = 4.4) were drawn from an established population at the UCSD Project in Cognitive and Neural Development. The LPBI group was originally composed of 16 participants, but one was ultimately excluded due to near-chance task performance. This population has been characterized in detail elsewhere (Stiles et al., 2012). Briefly, they suffered a single, unilateral neurological insult (nearly always secondary to stroke, typically arterial stroke or venous infarct), with the lesion documented by MRI or CT scan prior to six months of age. Perinatal histories were otherwise benign, aside from neonatal seizures that were presumed to be secondary to the insult. They had no significant uncorrected visual defects. Typically-developing participants (M = 15.0 years, SD = 5.1 years) were recruited from the community. They were all right-handed, and none had a history of neurological, psychiatric or major medical conditions, learning disability, head trauma, or current use of psychotropic drugs. Analysis of variance (ANOVA) revealed no differences in age across groups (RPBI, LPBI, TD), $F(2,43) = .008$, $p = .992$.

As part of their participation in the larger longitudinal PCND project, at some point prior to entering the current study all but two PBI participants (1 LPBI, 1 RPBI) had undergone intelligence testing with an age-appropriate Wechsler Intelligence Test: Wechsler Preschool and Primary Scale of Intelligence—Revised (WPPSI–R), Wechsler Intelligence Scale for Children—Revised (WISC–R), Wechsler Intelligence Scale for Children—Third Edition (WISC–III), Wechsler Intelligence Scale for Children—Fourth Edition (WISC–IV) (Wechsler, 1974, 1989, 1991, 2003). At the time of their participation in the current study, typically-developing participants underwent brief intellectual assessment with the Wechsler Abbreviated Intelligence Scale (WASI; Wechsler, 1999) or with a short form of the WISC-III (1 participant; (Sattler, 2001)), for the purpose of IQ matching with the PBI participants. IQ scores generated from these abbreviated assessments have been shown to be reliable and highly correlated with scores obtained from the full Wechsler battery (Sattler, 2001; Wechsler, 1999).