

Visuomotor Abilities in Children with Low Birth Weight: A Review and Suggestions for Future Research¹

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Children with low birth weight are defined as having a birth weight of less than 2,500 g. Due to improvements of medical technology, survival rates of LBW newborns are rising. Since some LBW children show visuomotor disabilities, these children need special educational support. Although researchers and parents understand the importance of appropriate educational treatment for LBW children, very little is currently known about the visuomotor and neurophysical abilities of these children. In the present paper, we reviewed studies of LBW children in terms of visuomotor deficits, developmental coordination disorder (DCD), and periventricular leukomalacia (PVL). The first topic deals with visuomotor abilities of LBW children; the second deals with DCD in LBW children; and the third with PVL in LBW children. On the basis of these topics, we proposed directions for future research that could lead to our further understanding of the visuomotor characteristics in these children.

Key words: Low birth weight (LBW), Visuomotor deficits, Developmental coordination disorder (DCD), Periventricular leukomalacia (PVL)

Visuomotor abilities in children with low birth weight: A review and suggestions for future research

Children with low birth weight (LBW) are defined by having a birth weight of less than 2,500 g.⁵ Researchers have associated LBW children with various obstetric risk factors, such as prenatal care, genitourinary infections, nutrition, using tobacco and drugs, and alcohol consumption (e.g., Offenbacher, Katz, Fertik, Collins, Boyd, Maynor, McKaig, & Beck, 1996). Although significant advances in medical technology have enhanced survival

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 5. Actually, children with low birth weight are classified as low birth weight children (LBW: birth weight < 2,500 g), very low birth weight children (VLBW: birth weight < 1,500 g), and extremely low birth weight children (ELBW: birth weight < 1,000 g).

rates of LBW children, these children often present with various types of visuomotor and neurodevelopmental impairments. In order to make decisions about appropriate special education for these children, basic visuomotor and neurophysical characteristics need to be revealed. Although some previous studies have examined these properties among LBW children, the investigations have been limited. In this paper, we reviewed previous studies that examined the visuomotor and neurophysical characteristics of LBW children. Specifically, we assessed studies dealing with visuomotor deficits, developmental coordination disorder (DCD), and periventricular leukomalacia (PVL). Based on these characteristics, we proposed future directions for examining LBW children's visuomotor abilities.

1. Cognitive abilities and visuomotor deficits in LBW children

Several studies have indicated that LBW children have lower IQ (intelligence quotient) scores compared with age-matched controls (birth weight > 2,500 g). Saigal, Szatmari, Rosenbaum, Campbell, and King (1991) showed that WISC-R (Wechsler Intelligence Scale for Children-Revised), full scale IQ (FSIQ) scores were 91 ± 16 for a LBW group and 104 ± 12 for an age-matched control group (mean age of 8 years old). Additionally, 8% to 12% of the LBW group had an abnormal IQ (FSIQ < 70), whereas 1% to 2% of the control group fell within this range (see also, Downie, Jakobson, Frisk, & Ushycky, 2003). Similar results were observed in other studies using various tests, such as the WPPSI (Wechsler Preschool and Primary Scale of Intelligence), K-ABC (Kaufman Assessment Battery for Children), Raven test (Raven's Colored Progressive matrices), and the Tanaka-Binet or Suzuki-Binet tests for preschool and school children (WPPSI: Vohr & Garcia-Coll, 1985; K-ABC: Jacobson, Frisk, Knight, Downie, & Whyte, 2001; Raven test: Saigal, Szatmari, Rosenbaum, Campbell, & King, 1990; Tanaka-Binet or Suzuki-Binet tests: Koeda & Takeshita, 1992). On the other hand, when LBW children make it into later childhood, many fall within a normal range of intelligence (Forsslund & Bjerre, 1990; Ornstein, Ohlsson, Edmonds, & Asztalos, 1991). Forsslund and Bjerre (1990) used Griffiths' mental developmental scale (Griffiths, 1970) to assess children's mental development and compared LBW (who were 4 years old and received follow-up treatment in a hospital for 4 years) and control children (birth weight > 3,000 g). This scale measures sensorimotor and intellectual development and is composed of six subscales, including locomotor, personal-social coordination, hearing-speech coordination, eye-hand coordination, performance, and practical reasoning scales. Almost all LBW children fell within the normal range for their age, although there were significant differences between LBW children and control children for some subscale scores. Thus, by receiving appropriate treatment, LBW children might be able to attain normal mental intellectual development. Moreover, LBW children frequently suffer from visuomotor deficits. In next topic, we review visuomotor deficits based on the developmental coordination disorder (DCD) among LBW children.

2. Developmental coordination disorder (DCD) among LBW children

Previous studies showed that 34% to 48% of LBW children had visuomotor deficits (Jongmans, Mercuri, Dubowitz, & Henderson, 1998; Powls, Botting, Cooke, & Marlow, 1995). These impairments are often diagnosed as developmental coordination disorder (DCD) based on DSM-IV-TR criteria (American Psychiatric Association, 2000). The prevalence of DCD has been estimated to be about 6% to 10% (DSM-IV: American Psychiatric Association, 1994) among school age children, given that these deficits are not typically recognized as mental disorders.

The Movement Assessment Battery for Children (MABC: Henderson & Sugden, 1992; MABC-2: Henderson, Sugden, & Barnett, 2007) has been a popular tool for measuring children's visuomotor deficits. The MABC is composed of three subtests: manual dexterity, ball skills (aiming and catching), and balance (static and dynamic). The test-retest reliability and internal consistency of the MABC are quite good (Chow & Henderson, 2003; Croce, Horvat, & McCarthy, 2001; Henderson & Sugden, 1992; Henderson et al., 2007; Van Waelvelde, de Weerd, de Cock, Janssens, Feys, & Smiths-Engelsman, 2006). According to the MABC, children are classified as having normal motor skills when they achieve scores over the 15th percentile, suspect motor competency when their scores ranged within the 15th to 5th percentiles, and definite motor problems when scores are below the 5th percentile. MABC scores ranging between the 6th and 15th percentile are associated with significant psychological risks, such as learning, attention, and adjustment deficits (e.g., Dewey, Kaplan, Crawford, & Wilson, 2002). Previous studies have examined the relationship between individual differences in MABC scores and perceptual tasks performances. Asonitou, Koutsouki, Kourtessis, and Charitou (2012) compared visuomotor performance between children (5 to 6 years-old) with and without DCD as measured by the MABC. The authors used the Bruininks-Oseretsky Test of Proficiency (BOTMP: Bruininks, 1978), which measures running speed, and the Das-Naglieri Cognitive Assessment System (CAS: Naglieri & Das, 1997), which measures planning, attention, and simultaneous coding. Results showed that all of the visuomotor measures for children with DCD were lower than that for children without DCD. Gheysen, Van Waelvelde, and Fias (2011) compared the abilities of visuomotor sequence learning between children (9 to 10 years-old) with and without DCD as measured by the MABC-2. In addition, the authors used a serial reaction time task (Nissen & Bullemer, 1987) to assess sequence learning speed. The children were asked to press a key as fast and accurately as possible corresponding to the location of the stimulus on a screen. Children with DCD showed longer reaction times than did children without DCD. DCD was associated with impairments in the dorsal stream, which is related to visuomotor task (Van Braeckel, Butcher, Geuze, van Duijn, Bos, & Bouma, 2008). Therefore, the MABC might be a good indicator for evaluating the magnitude of DCD related to dysfunction in the dorsal stream (Wilson, 2008).

Although the MABC has been considered a reliable and useful measure for identifying children's movement abilities, recent studies have proposed other measures, such as the

Developmental Coordination Disorder Questionnaire (DCDQ: Wilson, Kaplan, Crawford, Campbell, & Dewey, 2000; Wilson, Crawford, Green, Roberts, Aylott, & Kaplan, 2009), the Berry-Buktenica Developmental Test of Visual-Motor Integration (VMI: Beery, Buktenica, & Beery, 2010), and the Developmental Test of Visual Perception (DTVP-2: Hammill, Pearson, & Voess, 1993). The DCDQ is composed of 17 items assessing parent's reports of their children's motor abilities by using a 5-point Likert scale. The DCDQ assesses various movement abilities, such as throwing a ball, writing speed, and team sports. A significant correlation between the DCDQ and the MABC has been observed (Wilson et al., 2000). The VMI and DTVP-2 assess visual perception and visuomotor integration abilities, in addition to movement abilities. Wilson and McKenzie (1998) reviewed previous studies and indicated that visual ability is associated with deficits in motor coordination. Thus, by using these tests in addition to the MABC, researchers have extensive data in terms of not only movement abilities but also visual abilities.

Previous research suggested that DCD might be caused by a motor handicap or strabismus (e.g., Abercrombie, 1964). However, recent studies have reported new evidence that DCD might be caused by brain injury, particularly Periventricular leukomalacia (PVL), rather than a motor handicap or strabismus (Koeda & Takeshita, 1992). Next, we review PVL in LBW children.

3. Periventricular leukomalacia (PVL) in the LBW children

Several researchers have recognized PVL as a potent risk factor for neurological impairment among LBW children. PVL is a brain injury that is bilaterally localized within the parietal and occipital lobes (Holling & Leviton, 1999). This disease has a prevalence rate of 10% to 25% among LBW children (Trounce, Rutter, & Levene, 1986; investigated very low birth weight [VLBW] children, whose birth weight was less than 1,500 g). PVL includes white matter problems, such as softening of the periventricular white matter (Banker & Larroche, 1962) and lesions that extend into the deep white matter and the periventricular white matter area (Leech & Alvord, 1974). These injuries are associated with the thinning of parietal or occipital white matter among children with PVL (Goto, Ota, Iai, Sugita, & Tanabe, 1994). Kashiwagi, Iwaki, Narumi, Tamai, and Suzuki (2009) showed that DCD children demonstrate less activation in the left posterior parietal cortex (PPC) during a visuomotor task. The PPC is associated with integration of multimodal perceptual information related to motor activation, as well as generating mental representations of movements. Specifically, the left PPC has a role in motor control, whereas the right PPC has a role in imitation of other's actions (Iacoboni, 2006). Thus, weak PPC activation induces deficits in visuomotor integration. Since the PPC is not fully functional among DCD children, these children may generate weak mental representations or imagery. This might be the cause of these children's visuomotor deficits and coordination disorder. In contrast, LBW children without PVL (who were at an appropriate size for their gestational age) showed no deficits as compared with control children (Downie,

Frisk, & Jakobson, 2005; Frisk & Whyte, 1994). Downie et al. (2005) compared intellectual (WISC-III), academic (reading and spelling), and cognitive abilities (auditory working memory) between LBW children (birth weight < 1,000 g, 11 years old) with PVL, without PVL, and control children. The LBW children with PVL showed lower scores than LBW children without PVL and control children on all measures, whereas there were no significant differences on these measures between LBW children without PVL and control children. These findings suggest that PVL, not a prematurity status alone, affects acquisition of visuomotor skills among LBW children. On the basis of these results, we suggest future research for providing additional knowledge related to revealing visuomotor deficits among LBW children.

4. Suggestions for future research: examination of visuomotor abilities among LBW children in terms of DCD and PVL using a mental rotation task

In the present paper, we reviewed visuomotor deficits among LBW children in terms of DCD and PVL. First, LBW children frequently represent visuomotor deficits; these visuomotor deficits might result from DCD. DCD might be associated with white matter problems, particularly as related to PVL. Previously, visuomotor deficits resulting from DCD have been examined with a mental rotation task (Gabbard, Cacola, & Bobbio, 2011; Lust, Geuze, Wijers, & Wilson, 2006; Wilson, Maruff, Buston, Williams, Lum, & Thomas, 2004).

Mental rotation tasks are useful for an examination of generating and manipulating mental representations. Shepard and Metzler (1971) showed that time increments are required for each degree of angular disparity between standard and comparison objects when participants compare two objects at different orientations. Since participants mentally rotate the objects as if the objects are rotated physically, response times are longer depending on the degree of orientation. Previously, studies have indicated that preschoolers cannot conduct mental rotation tasks (e.g., Dean & Harvey, 1979; Piaget & Inhelder, 1966). Typically, mental rotation ability first appears at around 7 to 8 years old when using geometric shapes configured in three dimensions. In contrast, Marmor (1975, 1977) found that 5 years old preschoolers could perform a mental rotation task by using stimuli consisting of a panda bears and a cone. Due to the influence of experimental stimuli, Perrucci, Agnoli, and Albiero (2008) criticized the methodological problems of previous studies (Dean & Harvey, 1979; Piaget & Inhelder, 1966) that suggest preschoolers cannot understand geometric stimuli and are unable to conduct mental rotation tasks. Thus, preschoolers (5 years old) can perform mental rotation tasks when concrete and uncomplicated stimuli, such as the panda bears or cones proposed by Marmor (1975, 1977), are used. The processing stages of mental rotation are composed of 4 steps: encoding the comparison stimuli, rotating the stimuli, comparing the standard and comparison stimuli, and responding as to whether standard and comparison stimuli are the same or different (Kosslyn, 1994). Mental rotation tasks are associated with functioning in dorsal areas of the visual cortex related to the tracking of moving objects and encoding spatial

relations (Cohen, Kosslyn, Breiter, DiGirolamo, Thompson, Anderson, Bookheimer, Rosen, & Belliveau, 1996).

Some previous studies have examined the relationship between mental rotation task performance and the MABC in children with DCD. For example, Gabbard et al. (2011) examined the correlation between MABC scores and mental operation task performance. The children (7 to 10 years old), who had no DCD diagnosis, performed a mental operation task, which assessed their ability to mentally represent an action by estimating the reach distance between the child's hand and a target. Results showed a positive relationship between MABC scores and mental operation task performance; a better reaching estimate was connected with a higher MABC score. Wilson et al. (2004) compared MABC scores and performance on a hand rotation task between children (8 to 12 years old) with and without diagnosed DCD. MABC scores for DCD children were lower than that of control children. According to these results, control children have typical mental rotation performance: response times slowed with increased rotation angle. In contrast, DCD children showed atypical mental rotation performance: there were weak correlations between response time and rotation angle. This suggests that DCD children cannot enlist motor imagery while performing mental rotation tasks.

According to these results, we argue that the mental rotation paradigm is very useful for investigating visuomotor deficits in LBW children with DCD and PVL. Several previous studies have used mental rotation paradigms. In addition, previous studies have revealed a relationship between DCD and mental rotation ability. Although some LBW children have DCD, no studies to have assessed mental rotation task performance specifically among LBW children. A mental rotation task may provide valuable evidence of specific perceptual and visuomotor deficits among LBW children.

Future studies might provide with additional knowledge regarding visuomotor deficits among LBW children. Children in such studies might be theoretically classified as (1) LBW children with DCD and PVL, (2) LBW children with DCD but not diagnosed PVL, (3) LBW children without DCD and PVL, and (4) control children. LBW children frequently represent DCD (Forslund & Bjerre, 1990) related to PVL (Koeda & Takeshita, 1992). PVL is associated with the atrophying or thinning of parietal and occipital areas (Holling & Leviton, 1999). Mental rotation abilities are also associated with these areas (Cohen et al., 1996). From this perspective, when comparing mental rotation performance among these children, we might expect control children (4) to show the best performance. When DCD is the main factor associated with mental rotation performance, LBW children without DCD and PVL (3) might show higher performance than children with DCD (1 and 2). Moreover, if PVL is the potent factor related to mental rotation performance, LBW children with DCD, but not diagnosed PVL (2), might have higher performance than LBW children with DCD and PVL (1).

Such future research might provide behavioral evidence of visuomotor deficits associated with DCD and PVL. Because early special support education and treatment are necessary for LBW children, researchers should find an appropriate psychological index that can

successfully assess the degree of visuomotor deficits including deficits related to DCD and PVL. Depending on the evidence of future studies, the mental rotation task may be used as a psychological index for measuring the degree of visuomotor deficits among LBW children.

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