Objective. Our objective was to perform a meta-analysis to investigate whether low birthweight (LBW) or preterm birth was associated with difficulty in mental, neuromusculoskeletal, and movement-related school function tasks.

Method. Two search strategies produced 40 studies that met the inclusion criteria for the meta-analysis and yielded 549 effect sizes (d). Heterogeneity was evaluated by obtaining Q and I-squared values. Egger’s regression intercept test and a funnel plot were used to check for publication bias.

Results. Children born LBW exhibited considerable difficulties in mental (d = −0.655, p < .0001) and neuromusculoskeletal and movement-related tasks (d = −0.391, p < .0001) compared with children of normal birthweight. Children born preterm also exhibited significant difficulties compared with full-term children in mental, neuromusculoskeletal, and movement-related tasks (d = −0.237, p < .0001).

Conclusion. Deficits in mental and motor functions in children born LBW or preterm appear to have significant effects on school readiness and academic achievement.

In 2009, 8.2% of all babies were born with low birthweight (LBW; <2,500 g), and another 1.5% were born with very low birthweight (<1,500 g). In addition, 12.7% of total births were preterm (<37 wk gestation; U.S. Department of Health and Human Services [HHS], 2013). These statistics have remained steady, because the modifiers suspected of contributing to these figures have yet to be improved upon (HHS, 2013). These modifiers include low socioeconomic status, poor health literacy, low level of education, increased length of stay in the hospital, and secondary or associated diagnoses (Anderson & Doyle, 2003; Pritchard et al., 2009; Roberts, Lim, Doyle, & Anderson, 2011).

Studies have shown a direct correlation between infants born LBW or preterm across various outcome measures associated with school readiness and achievement in relation to their typically developing cohorts (Aarnoudse-Moens, Smidts, Oosterlaan, Duivenvoorden, & Weisglas-Kuperus, 2009; Anderson & Doyle, 2003; Gidley Larson et al., 2011; Oliveira, Magalhães, & Salmela, 2011; Pritchard et al., 2009; Roberts et al., 2011; van Baar, Vermaas, Knots, de Kleine, & Soons, 2009). Specifically, cognitive deficits, motor deficits, school difficulties, and behavioral problems have been shown to contribute most to low school readiness in these children (Anderson & Doyle, 2003). Considerable evidence supports the idea that children born preterm exhibit problems related to mental functions (Johnson, Wolke, Hennessy, & Marlow, 2011; Luu, Ment, Allan, Schneider, & Vohr, 2011). Although there is a link between cognitive deficits and poor scholastic performance,
cognitive deficits also negatively affect daily life functions (Anderson & Doyle, 2003). Subtle dysfunctions such as cognitive deficits, learning disabilities, attention problems, behavioral problems, and neuropsychological deficits become evident in approximately 50%–70% of children born preterm once they reach school age (Sullivan & Hawes, 2007).

Adolescents who were born preterm, compared with those born full term, have shown significant deficits in executive functioning: tasks related to verbal fluency, inhibition, cognitive flexibility, planning and organization, working memory, and verbal and visuospatial memory showed the highest levels of impairment (Luu et al., 2011). Cognitive impairments including phonological processing, attention, and executive functions also have been associated with academic attainment and educational outcomes (Johnson et al., 2011). Additionally, processing speed and working memory are important contributors to academic performance (Mulder, Pitchford, & Marlow, 2010).

It has also been well established that preterm infants are delayed in motor function compared with children born full term (Sullivan & Hawes, 2007). Motor deficits such as atypical posture, delayed crawling, delayed walking, and delayed sitting are common in preterm infants. Atypical posture may include hyperextension of the neck and trunk and reduced active flexion power and head lag. The condition of high tone has been shown to decrease over time, giving it the name transient dystonia (Pin, Darrer, Eldridge, & Galea, 2009, p. 739). Natural variations in a child's development must always be taken into consideration and acknowledged. To gain a clear understanding of a child's motor performance, the child should be observed over a period of time and not just on one occasion (Pin et al., 2009).

Minor mental disability, such as learning disabilities, poor social skills, and low self-esteem, occurs in 5%–15% of normal birthweight children, but it is significantly higher in children born premature or at extremely low birthweight (ELBW; <1,000 g; Drotar et al., 2006). Associated minor motor disabilities, such as developmental dyspraxia, perceptual–motor dysfunction, clumsiness, mild motor problems, and sensory integration dysfunction, have been identified in preterm and ELBW children (Johnson et al., 2011). Various labels have been discussed in an effort to name this cluster of symptoms in preterm children.

An abundance of evidence exists supporting the significance of the previously mentioned deficits in LBW or preterm children because it is apparent that LBW or preterm infants grow and develop at a much slower pace than their typically developing cohorts (Anderson & Doyle, 2003; Gidley Larson et al., 2011; Pritchard et al., 2009; van Baar et al., 2009). It has become a societal issue to be able to successfully respond to the unique needs of these children, help them mature to their full capacity, and do so with the least amount of financial burden possible. Retrospectively, preventive measures used in treating the developmental needs of these children have been shown to be the most cost-effective mechanism long term (Drotar et al., 2006; Institute of Medicine, Committee on Understanding Preterm Birth and Assuring Healthy Outcomes, 2007).

Multiple studies have reported on the mental, neuromusculoskeletal, and movement-related function deficits present in LBW or preterm children once they enter school. However, these studies have used a variety of instruments, have varying sample sizes, and have a high degree of heterogeneity. Therefore, an urgent need exists to compile the research literature to form conclusive evidence of an association among mental, neuromusculoskeletal, and movement-related function delays in children born LBW or preterm so that a targeted early intervention can be established.

The aim of this study was to perform a meta-analysis on the existing research literature data to calculate the central tendency of the mean effect size across studies of mental, neuromusculoskeletal, and movement-related function delays in relation to school achievement in children born LBW or preterm. A meta-analysis allows researchers evaluate moderators like LBW or preterm birth, which are known to cause variation between the populations being studied. A meta-analysis is primarily reliant on effect size, and reliance on statistical significance is decreased. On the basis of the current research, we proposed the hypothesis that infants born LBW or preterm would have an inherent deficit in mental, neuromusculoskeletal, and movement-related functions that would be evident once they are at school age.

Method

Sample of Studies

We collected data from studies that compared children who were born LBW or preterm with their typically developing peers on measures of mental, neuromusculoskeletal, and movement-related functions associated with school readiness and achievement. Two different search techniques were used to analyze studies for inclusion in the meta-analysis. First, a computerized literature search within ScienceDirect, ERIC, OneFile, SpringerLink, Wiley Online, PubMed, CINAHL, Oxford Journals, Web of Science, and Education Full Text was performed using the following key terms: low birth weight, preterm, cognitive/cognition, motor, developmental delay, school-readiness, achievement, difficulties, function, and children–pediatrics. All key terms were used in a variety of combinations to retrieve all desired materials. The key terms were chosen because the aim of this
meta-analysis was to examine the strength of the association between the mental, neuromusculoskeletal, and movement-related performance of children who were born LBW or preterm and school readiness and achievement. This expansive variety of key terms was used to ensure that all variations of children born LBW or preterm and impairments in mental, neuromusculoskeletal, and movement-related functions would be represented in the search inquiry. Second, references and citations of obtained studies were scrutinized for other compatible publications.

Selection

Each article was further examined to distinguish whether the studies satisfied the following inclusion criteria: (1) disseminated or accessible in English between 2000 and December 2012; (2) original studies; (3) included only children between ages 0 and 21 who were born LBW or preterm; (4) existence of a healthy, typically developing comparison group; (5) mental, neuromusculoskeletal, and movement-related functions tested using standardized and non-standardized cognitive and motor skills assessments; and (6) test scores (standard deviations [SDs] and means [Ms]) available for effect size calculation. No minimum sample size was set as a part of the inclusion criteria for analysis. Exclusion of studies took place if they did not meet inclusion criteria requirements or if the outcomes of the study did not allow for calculation of the effect size (Ottenbacher, Heyn, & Abreu, 2009).

Data Extraction and Coding of Studies

For each study, the following information was extracted and coded: (1) authors and year; (2) whether the child was born with LBW or preterm; (3) sample size; (4) client factors that correspond with the Occupational Therapy Practice Framework: Domain and Process (2nd ed.; American Occupational Therapy Association, 2008); (5) summary of the mental, neuromusculoskeletal, and movement-related functions testing provided; and (6) test results (SD and M) required for computation of effect sizes. All pertinent information was entered into an Excel spreadsheet. The coding strategies for mental, neuromusculoskeletal, and movement-related functions test subdivisions were based on methods previously established by Wilson and McKenzie (1998). For the purposes of this meta-analysis, the following definitions (World Health Organization, 2012) were used:

- LBW: <2,500 g
- Normal birthweight: ≥2,500 g
- Preterm: <37 wk gestation
- Full term: ≥37 wk gestation

Both the LBW and preterm groups were compared with normal birthweight and full-term groups in the Framework body function areas of mental, neuromusculoskeletal, and movement-related functions. The studies were coded into the following categories:

- LBW and mental functions assessments
- LBW, neuromusculoskeletal, and movement-related functions assessments
- Preterm and mental functions assessments
- Preterm, neuromusculoskeletal, and movement-related functions assessments.

Quantitative Data Synthesis

Effect Size. The effect sizes were computed using Comprehensive Meta-Analysis software (Borenstein, Hedges, Higgins, & Rothstein, 2005). This software was used to calculate the effect sizes for mental functions assessment and neuromusculoskeletal and movement-related functions assessment with LBW or preterm groups for uncontrolled and controlled studies. Effect size is calculated as the ratio of the mean difference between the experimental and comparison group divided by the standard deviation of the comparison group. The software automatically computed effect sizes (d), Fisher’s Z, and other values using SDs, Ms, and sample sizes. Effect size (d) values of 0.2, 0.5, and 0.8 were considered to have small, medium, and large effects. Fisher’s Z was useful for combined meta-analysis because it was less affected by small sample bias (Rosenthal, 1991). For each effect size estimate, a standardized M difference and 95% confidence intervals were calculated in a fixed- and random-effects model. To calculate the size of the overall effect, we found that the positive (+) sign of effect demonstrates better effects than the comparison group and the negative (−) sign of effect indicates that the converse was true.

Heterogeneity Test. The Q and I-squared values were obtained to evaluate heterogeneity. Heterogeneity is a major contributor to meta-analyses because heterogeneity statistics provide data about variability within and between studies. I-squared values of 0, 25, 50, or 75 represent no, low, medium, or high heterogeneity between studies. Both fixed- and random-effects models were examined and presented, because the software performed both analyses at the same time. However, a fixed-effects model generally is used for homogeneous effect sizes and a random-effects model for heterogeneous effect sizes (Shiroma, Ferguson, & Pickelsimer, 2010). Test for Publication Bias. Publication bias refers to the likelihood of research to report positive results. When conducting a literature search for a meta-analysis, the researcher is more likely to locate studies that report mostly positive effects, thus biasing the results of the meta-analysis. Egger’s regression intercept test and a funnel plot were used to check for publication bias in this research. Using a funnel plot, researchers can visually check for standard errors by signaling the effect size on the horizontal axis. The funnel
plot will lean to one side, taking on an asymmetrical form, if publication bias exists. Publication bias is insignificant if the p value is above .05 in Egger’s regression intercept test (Egger, Davey Smith, Schneider, & Minder, 1997).

Results
Sixty-nine studies were identified after using two search strategies. Nineteen studies were excluded from the meta-analysis because they did not have data from a comparison group. Additionally, 6 of the articles did not include the means or standard deviations. Only z scores were given; therefore, the effect size calculations would be skewed. Another 4 of the studies used a parental perception questionnaire and did not use assessments for mental, neuromusculoskeletal, and movement-related functions.

Ultimately, 40 studies met the inclusion criteria and were included in the meta-analysis table. These studies included 6,553 children born LBW or preterm and 24,624 typically developing children. These data yielded 549 effect sizes, representing the total number of mental, neuromusculoskeletal, and movement-related measures included in the meta-analysis. Mental functions assessments in 38 studies included IQ; attention; executive function (working memory, processing speed, inhibition, etc.); emotional–behavioral characteristics; and academic areas of reading, math, and spelling. Eleven studies included assessments in neuromusculoskeletal and movement-related functions such as visual–motor, perceptual–motor, hand skill, sensory–motor, and motor coordination and control.

Comparison of Children Born LBW and Children of Normal Birthweight

Seven hundred forty-five children were included in 8 studies comparing children born with low and normal birthweight. For each category, the strength of association on measure by effect size of LBW, mental function, and neuromusculoskeletal and movement-related functions is medium in the current study. Using fixed-effects analysis, the df for mental function was −0.630 (p < .0001) and for neuromusculoskeletal and movement-related functions was −0.556 (p < .0001).

Using random-effects analysis, the df for mental function was −0.655 (p < .0001) and for neuromusculoskeletal and movement-related functions was −0.391 (p < .0001). The Q was 500.891, p < .0001, and the I-squared was 74.046, suggesting a high degree of heterogeneity. The random-effects analysis was used to assess variability within and between studies (Table 1).

Comparison of Children Born Preterm and Children Born Full Term
A total of 5,808 children were included in 32 studies comparing children born preterm and full term. For each category, the strength of association on measure by effect size of preterm, mental function, neuromusculoskeletal, and movement-related function was small. Using fixed-effects analysis, the df for mental function was −0.188 (p < .0001) and for neuromusculoskeletal and movement-related functions was −0.004 (p < .882). Using random-effects analysis, the df for mental functions was −0.263 (p < .0001) and for neuromusculoskeletal and movement-related functions was 0.068 (p < .358). The Q was 4922.136, p < .0001, and the I-squared was 91.528, suggesting a high degree of heterogeneity. The random-effects analysis was used to assess variability within and between studies (Table 2).

Table 1. Comparison of Children Born LBW and Children of Normal Birthweight

<table>
<thead>
<tr>
<th>Category</th>
<th>No. of Items Extracted From Studies</th>
<th>Effect Size</th>
<th>Heterogeneity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>d</td>
<td>Z</td>
</tr>
<tr>
<td>Fixed-effects analysis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mental functions</td>
<td>93</td>
<td>−0.630</td>
<td>−39.548</td>
</tr>
<tr>
<td>Neuromusculoskeletal and movement-related function</td>
<td>38</td>
<td>−0.556</td>
<td>−15.444</td>
</tr>
<tr>
<td>Overall</td>
<td>131</td>
<td>−0.617</td>
<td>−41.484</td>
</tr>
<tr>
<td>Random-effects analysis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mental functions</td>
<td>93</td>
<td>−0.655</td>
<td>−22.555</td>
</tr>
<tr>
<td>Neuromusculoskeletal and movement-related function</td>
<td>38</td>
<td>−0.391</td>
<td>−4.011</td>
</tr>
<tr>
<td>Overall</td>
<td>131</td>
<td>−0.634</td>
<td>−22.761</td>
</tr>
</tbody>
</table>

Note. df = degrees of freedom; — = not applicable.

*p < .05.
Discussion

This meta-analysis has statistically demonstrated that children born LBW or preterm have an association with later delays in mental, neuromusculoskeletal, and movement-related functions. The results indicate that children born LBW or preterm made more mental function errors, took longer during decision-making tasks, and received lower scores on mental function assessments than their typically developing counterparts. In addition, children born LBW or preterm made more neuromusculoskeletal and movement-related errors, took more time to complete tasks, and received lower scores on neuromusculoskeletal and movement-related assessments than their typically developing counterparts. Overall, an adequate effect size was identified to prove the hypothesis that children born LBW or preterm are more likely to have mental, neuromusculoskeletal, and movement-related deficits once they reach school than children born normal birthweight or full term.

The results further suggest that birthweight and gestational age are significant predictors for long-term neurodevelopmental delay into adolescence. Bhutta, Cleves, Casey, Cradock, and Anand (2002) found that both birthweight and gestational age were significantly correlated with decreased cognitive scores and that those scores were consistent with an enriched risk of movement-related delay. Because the timing of testing in these children ranged from 4 mo into adolescence, it would be logical to interpret that the aforementioned delays persist well into adolescence. In fact, in a recent neuroimaging study, Spencer et al. (2008) documented abnormalities in brain structures of children born LBW or preterm that persisted long term. Specifically, Spencer et al. found that children born either LBW or preterm were associated with reduced gray matter density in the temporal brain structures and in the cerebellum that continued into childhood. This atypical brain structure and associated cortical dysfunction within the temporal lobe

Table 2. Comparison of Children Born Preterm and Full Term

<table>
<thead>
<tr>
<th>Category</th>
<th>No. of Items Extracted From Studies</th>
<th>Effect Size</th>
<th>Heterogeneity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>d</td>
<td>Z</td>
</tr>
<tr>
<td>Fixed-effects analysis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mental functions</td>
<td>320</td>
<td>-0.188</td>
<td>-32.795</td>
</tr>
<tr>
<td>Neuromusculoskeletal and movement-related functions</td>
<td>98</td>
<td>-0.004</td>
<td>-0.148</td>
</tr>
<tr>
<td>Overall</td>
<td>418</td>
<td>-0.180</td>
<td>-32.095</td>
</tr>
<tr>
<td>Random-effects analysis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mental functions</td>
<td>320</td>
<td>-0.263</td>
<td>-11.971</td>
</tr>
<tr>
<td>Neuromusculoskeletal and movement-related functions</td>
<td>98</td>
<td>0.068</td>
<td>0.919</td>
</tr>
<tr>
<td>Overall</td>
<td>418</td>
<td>-0.237</td>
<td>-11.219</td>
</tr>
</tbody>
</table>

Note. df = degrees of freedom; — = not applicable. *p < .05.

The results further suggest that birthweight and gestational age are significant predictors for long-term neurodevelopmental delay into adolescence. Bhutta, Cleves, Casey, Cradock, and Anand (2002) found that both birthweight and gestational age were significantly correlated with decreased cognitive scores and that those scores were consistent with an enriched risk of movement-related delay. Because the timing of testing in these children ranged from 4 mo into adolescence, it would be logical to interpret that the aforementioned delays persist well into adolescence. In fact, in a recent neuroimaging study, Spencer et al. (2008) documented abnormalities in brain structures of children born LBW or preterm that persisted long term. Specifically, Spencer et al. found that children born either LBW or preterm were associated with reduced gray matter density in the temporal brain structures and in the cerebellum that continued into childhood. This atypical brain structure and associated cortical dysfunction within the temporal lobe.

Figure 1. Funnel plot indicating publication bias.

Note. Std diff = standardized difference.
may result in poor cognitive functioning, because temporal lobe structures are important in memory, language, and learning. In addition, given the critical role of the cerebellum in motor functioning, cerebellar abnormalities in children born LBW or preterm have had persistent effects on problems with motor coordination (Davis, Ford, Anderson, & Doyle, 2007; Kesler et al., 2006).

Note that current literature has suggested that mental functions and movement-related functions are interrelated and interactive and that they develop codependently (Diamond, 2000). Therefore, it is not unlikely that one would find considerable associations between mental and movement-related functions in children born LBW or preterm. Traditionally, it has long been known that the prefrontal cortex plays a significant role in mental function, and the cerebellum is thought to be essential for motor development. However, several studies have reported that motor developmental delay presents concomitantly with cognitive deficits in children with wide range of developmental disorders, including attention deficit hyperactivity disorder, dyslexia, specific language disorder, and autism, suggesting that cognitive and motor systems might be tightly coupled (Chaix et al., 2007; Fliers et al., 2008; Noterdaeme, Wriedt, & Höhne, 2010). In addition, functional neuroimaging studies have shown that the cerebellum is activated in participants conducting cognitive tasks and that, conversely, motor tasks increased activation not only in the cerebellum but also in the dorsolateral prefrontal cortex (Diamond, 2000). Our meta-analysis further supports this notion of tight coupling between motor and cognitive functions.

The results of this study should allow early intervention professionals to begin to prioritize developmental areas where dysfunction is at risk of occurring. Multidisciplinary team members such as occupational, physical, and speech therapists and psychologists have been known to provide early intervention and education to LBW or preterm infants and children and their families (Koldewijn et al., 2009; Legendre, Burtnet, Martinez, & Crowe, 2011; Nordhov et al., 2010; Verkerk et al., 2011). Each professional brings his or her expertise and experience to the intervention team with the intention to provide support in his or her specialty and professional practice framework. Specifically, occupational therapy services, deemed to be a significant and effective early intervention for children born LBW or preterm, can influence their mental, neuromusculoskeletal, and movement-related abilities (Opp, 2009). Children born LBW or preterm may require long-term occupational therapy services in the form of early intervention, which can focus on deficits in mental, neuromusculoskeletal, and movement-related functions.

### Implications for Occupational Therapy Practice

This study’s findings have the following implications for occupational therapy practice:

- The results suggest the importance of an extensive and timely mental, neuromusculoskeletal, and movement-related assessment for children born LBW or preterm. Note that birthweight of most children born preterm is lower than that of children born full term, so often children born preterm exhibit LBW.
- The results of this study strongly indicate the need for early interventions that encompass both mental (cognitive) and motor activities in children born LBW or preterm to address difficulties associated with academic attainment and educational outcomes.
- Additionally, when setting up an early intervention program, occupational therapy practitioners should strongly consider incorporating cognitive developmental activities, especially in children born LBW, because these children show strong association with poor mental functions.

### Study Limitations

This meta-analysis has several limitations. Our study did not include unpublished studies and articles in languages other than English. Therefore, our results need to be interpreted cautiously. The results of the meta-analysis may have been influenced by publication bias, because studies with significant results are more likely to be published and to be included for meta-analysis (Macaskill, Walter, & Irwig, 2001).

### Conclusion

Our meta-analysis indicates that children born LBW or preterm are highly at risk for adverse effects on mental and neuromusculoskeletal and movement-related functions and on academic achievement compared with infants born at normal birth weight or full term. Occupational therapy practitioners have an essential role maximizing the potential

### Table 3. Egger’s Regression Intercept Test

<table>
<thead>
<tr>
<th>Result</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>−1.029</td>
</tr>
<tr>
<td>Standard error</td>
<td>0.251</td>
</tr>
<tr>
<td>95% lower limit (2-tailed)</td>
<td>−1.522</td>
</tr>
<tr>
<td>95% upper limit (2-tailed)</td>
<td>−0.536</td>
</tr>
<tr>
<td>t value</td>
<td>4.102</td>
</tr>
<tr>
<td>df</td>
<td>547</td>
</tr>
<tr>
<td>p</td>
<td>.000</td>
</tr>
<tr>
<td>p (two-tailed)</td>
<td>.000</td>
</tr>
</tbody>
</table>

Note. df = degrees of freedom.
for typical development and reinforcing development during a child’s life. Well-timed clinical services with early diagnosis are needed to curb academic problems. Treatment planning that includes both mental and movement activities would seem to be a more effective approach than treating each separately. ▲

Acknowledgment

This meta-analysis was part of the master’s project development in occupational therapy at Florida International University. We thank Florida International University for providing facilities and software to conduct this study.

References


*Indicates studies included in the meta-analysis.


