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Social Outcome Following Pediatric Traumatic Brain Injury: A Meta-Analysis

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Social Outcome Following Pediatric Traumatic Brain Injury:
A Meta-Analysis

Jonathan James Mietchen

A dissertation submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of
Doctor of Philosophy

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ABSTRACT

Social Outcome Following Pediatric Traumatic Brain Injury: A Meta-Analysis

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Objective: Children and adolescents with a history of traumatic brain injury (TBI) are at increased risk for developing social incompetence and impairment in broad psychosocial functioning. The aim of this study was to examine the relationship between history of TBI, social competence, and broad psychosocial functioning using meta-analytic methods.

Methods: Studies relating to social outcome following pediatric TBI were searched for using scientific, academic databases. Sixteen studies ($N=2,005$) met inclusion criteria, and relevant data relating to social functioning was extracted. Meta-analytic methods were used in order to obtain Hedges's g effect size data for mild, moderate, and severe TBI groups. Meta-regressions were also used to examine the effect of potential moderating variables, including Glasgow Coma Scale (GCS), socioeconomic status (SES), gender, control group (typically developing (TD) or orthopedic injury (OI)), and time/age related variables. Finally, publication bias was calculated using funnel plots and Rosenthal's fail-safe N .

Results: A dose-response effect was observed with mild (Hedges's $g = -0.387$), and moderate (Hedges's $g = -0.459$) groups demonstrating smaller effects when compared to the severe group (-0.814) on measures of broad psychosocial function. A dose-response effect was also observed on measures of social competence, with mild (Hedges's $g = -0.098$) and moderate (Hedges's $g = -0.450$) TBI groups demonstrating smaller effect sizes when compared to the severe TBI group (Hedges's $g = -0.832$). The GCS was a significant predictor of both broad psychosocial functioning ($B = 0.065, p < 0.001$) and social competence ($B = 0.079, p < 0.001$), such that more severe injuries predicted poorer social outcomes. Gender was a significant predictor of effect size ($B = 0.018, p = 0.05$), such that higher proportions of females was associated with smaller effect sizes. Finally, the type of control group used in these studies was also a significant predictor of effect size ($B = 0.369, p = 0.03$), such that studies that used TD produced larger effect sizes when compared to studies that used OI. Overall, there was little evidence for publication bias.

Conclusions: Children and adolescents with a history of TBI demonstrated significant differences from their peers in social competence and broad psychosocial functioning following TBI. The severity of the injury is important in understanding and predicting social outcomes following pediatric TBI. Implications of these findings are discussed.

Keywords: traumatic brain injury, social, meta-analysis, children, adolescents

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Social Outcome Following Pediatric Traumatic Brain Injury:
A Meta-Analysis

Traumatic brain injury (TBI) is one of the leading causes of childhood mortality and disability worldwide. Mild head injury represents a relatively large percentage of all childhood injuries, whereas severe head injury with considerable and persistent effects represent a smaller childhood population (Bean, 2016).

The incidence of pediatric brain injury over one year has been reported to be approximately 1.75%, while the prevalence for pediatric brain injury from birth to age 25 is reportedly 31.59% (McKinlay et al., 2008). Of these injuries, 67.03% are dealt with in an outpatient setting, and these are thought to make up more mild head injuries. Of these mild injuries, it is reported that about 81.9% of these children are first seen by their primary care physicians, 5.2% were first seen in specialty clinics, and about 11.7% were first seen in the emergency department (Arbogast et al., 2016). About 37.97% of these children with head injuries were admitted to the hospital for observation and about 12.39% of children with head injury had injuries of sufficient severity to merit at least one night in a hospital (McKinlay et al., 2008). Adolescents between 15-20 years of age have the highest risk of experiencing head injury due to the high risk of motor vehicle accidents. However, children age 0-5 years also experience similarly high risk of injury due to the high incidence of falls and other mishaps. With an overall childhood prevalence of head injury of 31.59% and the various mechanisms of injury, pediatric brain injury represents tragedy to the individuals and families involved, as well as a public health problem due to the chronicity of these injuries (Bean, 2016; McKinlay et al., 2008).

Neurologic Injury and Neuroanatomy of Social Competence

Fronto-temporal regions of the brain are substantially more susceptible to injury when compared to other neuroanatomic regions. In fact, both post-mortem, and neuroimaging studies demonstrate this fronto-temporal susceptibility and these findings have been replicated in children (Bigler, 2007; Courville, 1950; Yeates et al., 2007).

When examining regions susceptible to injury, there is a strong relationship to brain regions known to be involved in social competence, and much of the ‘social brain’ seems to reside in fronto-temporal structures (see Figure 1). Given the role of fronto-temporal structures susceptible to injury in social behavior, children who have sustained a TBI are at risk for experiencing social incompetence and poor social outcome following a head injury.

Consequently, this topic has been previously studied and is represented in the pediatric TBI literature (Rosema, Crowe, & Anderson, 2012).

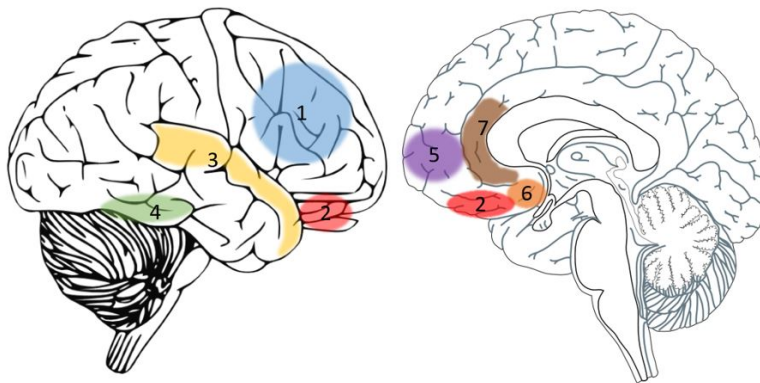


Figure 1. Brain regions that have demonstrated involvement in social competence.

1) Dorsolateral prefrontal cortex, 2) Orbitofrontal cortex, 3) Superior temporal gyrus, 4) Fusiform gyrus, 5) Medial frontal cortex, 6) Basal forebrain, 7) Anterior cingulate cortex.

*Adapted from <https://clipartion.com/?s=brain>

Table 1

Associations Between Neuroanatomical Regions Susceptible To Brain Injury, And These Regions' Association With Social Competence As Per Yeates et al., (2007).

| Brain Region | Role in social competence |
|---------------------------------|--|
| Amygdala | Emotion recognition |
| Basal forebrain | Modulation of cognition |
| Cingulate cortex | Modulation of cognition |
| Dorsolateral pre-frontal cortex | Executive functions and working memory |
| Fusiform gyrus | Face perception |
| Hippocampus | Modulation of cognition; Emotional memory retrieval |
| Medial frontal cortex | Theory of mind; Emotion regulation; Monitoring social outcomes |
| Ventral Striatum | Motivational evaluation |
| Orbitofrontal cortex | Self-regulation; Theory of mind |

Broad Psychosocial Functioning and Social Competence

The methodology of studies evaluating social outcome following pediatric TBI requires consideration. A majority of studies have utilized indirect measurement of social competence, including parent-report questionnaires of their child's social skills. Two of the most common measures that have been used are the Vineland Adaptive Behavior Scales (VABS) and the Child Behavior Checklist (CBCL) (Rosema et al., 2012). The Adaptive Behavior Assessment System (ABAS) and Preschool and Kindergarten Behavior Scales (PKBS-2) have also been used to assess psychosocial functioning following pediatric TBI (Rosema et al., 2012). While these measures are uniquely formatted to assess the child's daily social competence, and are often thought to be ecologically valid, they are not direct measures of the child's social competence and social cognition.

For the purposes of this meta-analysis, it is important to make a clear distinction between broad *psychosocial* functioning measures, and measures specific to *social competence*. Many of the parent-reported measurements described above contain both a measure of broad psychosocial

functioning and a scale specific to social competence. For example, the VABS has several subscales including communication, daily living skills, socialization, motor skills, and a maladaptive behavior index. The CBCL includes scales related to social problems, anxiety, depression, aggression, and defiance. These subscales from these measures are often combined to make up an overall composite score that we refer to as broad *psychosocial functioning*. While these composite scales seem to lack specificity regarding specific problem areas, they offer information regarding the child's daily psychosocial functioning as a whole, and these measures are often used in the pediatric TBI literature.

In regards to specific social competence measures, these broad measures of psychosocial function often include subscales related specifically to how these children function in social situations. For example, the VABS includes a Socialization scale that provides information regarding the child's interpersonal interactions, and play with other children. The CBCL is also similar in this way, in that it provides information regarding social challenges that children may experience, and does so with the Social Problems Scale. These subscales, and others, specific to social abilities are referred to as *social competence*. While these two terms refer to different competencies and functions, both psychosocial functioning and social competence can broadly be categorized as *social outcome*, and for our purposes, social outcome specifically related to and following TBI.

Social Outcome Following TBI

Research regarding social outcome following pediatric TBI has demonstrated quite clearly that children with TBI experience poor psychosocial functioning and are at greater risk for developing poor social competence (Rosema et al., 2012). Children who have experienced a TBI have reported poorer social skills, higher degrees of loneliness, lower self-esteem, and poor

social problem-solving abilities (Andrews, Rose, & Johnson, 1998; Ganesalingam, Sanson, Anderson, & Yeates, 2006; Hanten et al., 2008). While some children with TBI are able to generate solutions to social problems, they often generate sub-optimal solutions to those problems (Janusz, Kirkwood, Yeates, & Taylor, 2002). Further, children who have sustained an injury often display poorer social communication compared to normally developing peers (Asarnow, Satz, Light, Lewis, & Neumann, 1991; Levin, Hanten, & Li, 2009; Papero, Prigatano, Snyder, & Johnson, 1993; Poggi et al., 2005).

Across the various studies, several have examined the effect of injury severity on psychosocial outcome and social competence. Children who have sustained a severe TBI have reportedly higher rates of social conflict when compared to not only a control group, but also when compared to children who have sustained mild to moderate TBI (Bohnert, Parker, & Warschausky, 1997). Children with severe TBI show both poor psychosocial functioning, and diminished social competence. (Chapman et al., 2010; Fletcher, Ewing-Cobbs, Miner, Levin, & Eisenberg, 1990; Ganesalingam et al., 2011; Max et al., 1998; Prigatano & Gupta, 2006; Yeates et al., 2004; Yeates, Taylor, Walz, Stancin, & Wade, 2010)

Although the majority of studies have used questionnaire measures, there are some studies that used direct, lab-based measures of social competence (Rosema et al., 2012). To date, three studies have used the Interpersonal Negotiation Strategies task as a measure of social problem-solving (Hanten et al., 2011; Hanten et al., 2008; Janusz et al., 2002). These studies using the INS demonstrated and replicated that children with TBI were deficient in their ability to problem-solve using social-related information. Theory of mind and emotion recognition is another domain that has been studied consistently. Theory of mind refers to the ability to take the perspective of another individual and to use that perspective to understand how that person is

thinking or feeling (Imuta, Henry, Slaughter, Selcuk, & Ruffman, 2016). Previous studies have shown that children with TBI may struggle to understand and perceive the emotions and thoughts of others, which is thought to represent impairment in theory of mind (Dennis et al., 2013; Dennis et al., 2012; Schmidt, Hanten, Li, Orsten, & Levin, 2010).

Socioeconomic status and social outcome following TBI. Although widely studied, the precise definition of socioeconomic status (SES) remains unclear (Bradley & Corwyn, 2002). A common perception of SES refers to an individual or family's financial capital. However, SES likely embodies other factors such as social status, and human capital (including nonmaterial assets, such as education) (Coleman, 1988). Because SES can potentially serve as a proxy for various social factors, it is not surprising that SES is a significant predictor of several developmental and childhood outcomes (Bradley & Corwyn, 2002).

SES has been associated with neural development in utero and neurobehavioral development after birth and has been associated with multiple health outcomes, academic performance, and emotional health (Bradley & Corwyn, 2002; DiPietro, Costigan, Hilton, & Pressman, 1999; Duncan, Brooks-Gunn, & Klebanov, 1994). Socioeconomic status also seems to be directly related to social competence in children who have not experienced a head injury. Children from low SES have been reported by their teachers to be less socially competent when compared to their middle SES peers (Ramsay, 1988).

Research explicitly examining the relationship between SES and social outcome following pediatric TBI is scarce. Some studies, however, have reported a significant direct effect of SES on pediatric TBI social outcome. Taylor et al. (2002) examined the relationship between SES and overall behavior problems as measured by the CBCL and found a group x SES interaction in which lower SES was associated with more behavior problems in children with

TBI than that of their normally developing peers, and that these differences grew larger with lower SES. These authors also found that lower SES seemed to hinder development of social competence in children with TBI.

Yeates et al. (2004) demonstrated that SES was predictive of social competence scales on the CBCL and the VABS. Similarly, Chapman et al. (2010) demonstrated that SES was a significant predictor of social competence and behavioral disturbance following pediatric TBI such that lower SES was predictive of more social and behavior problems.

Age at injury and social outcome. Similar to the effects of SES on social competence following pediatric TBI, the association between age at injury and social competence is unstudied. Despite the small number of studies examining the direct relationship between age at injury and social competence, age at injury is thought to contribute to social outcome, with younger age at injury being predictive of poorer social development (Rosema et al., 2012). Donders and Warschausky (2007) examined several neurobehavioral outcomes between adolescents who suffered a TBI younger than age 12 years, and those who suffered a TBI older than age 16 years. Adolescents who were injured prior to age 12 years showed significantly poorer social integration than those who were injured after age 16 years.

Hanten et al. (2008) also demonstrated a significant effect for age at injury on social competence. More specifically, they examined the relationship between lesion location and social problem solving. Their findings showed that lesion location was an important predictor of social problem solving, with frontal lobe lesions being most predictive. Children receiving frontal lobe lesions at a younger age showed poorer social problem solving abilities than children who received their frontal lobe injuries at an older age. This apparent interaction between age at injury and frontal lesions may be due to the disruption of normal social development, which is

often associated with the development of the anterior portions of the brain, including the frontal lobes (Yeates, 2010).

Time post injury and social outcome. The effect of time after injury on social competence has a small research base. In one of the few relevant studies, Anderson and colleagues (2006) examined children's broad psychosocial functioning and social competence using the VABS and the Personal Inventory for Children (PIC). Examining children's psychosocial and social competence in the acute phase of injury, 12 months post-injury, and 30 months post injury, the authors found a significant interaction between severity and time post injury in predicting social competence and broad psychosocial functioning on the VABS, as well as psychosocial functioning on the PIC. Specifically, the authors found that children with severe TBI experienced a significant "fall-off" in adaptive and social skills at 30 months post injury compared to their skills at 12 months post injury.

In contrast to the findings mentioned above which examined all severities, Anderson and colleagues (2006) examined the outcome from mild head injury alone in young children aged 3-7 years. In this sample, there were no differences in social competence in children with mild head injury (defined as a GCS of 13-15 without positive neuroimaging findings) in the acute stage, 6 months post injury, or 30 months post injury. A more recent study conducted by Yeates et al., (2010) found weak support that time since injury was a significant predictor of psychosocial function as measured by the CBCL, ($p = 0.06$). However, there was more support that interactions of other variables such as authoritarian parenting, injury severity, permissive parenting, and the home environment with time since injury were involved.

Meta-analytic methods have several advantages and are able to accomplish particular aims that individual studies and narrative reviews cannot (Cheung & Vijayakumar, 2016). When

utilizing meta-analysis, the systematic review and search of the literature allows for replication of search strategies. A meta-analysis is also able to account for characteristics of the sample using quantitative methods in order to determine whether sample characteristics of these studies account for a significant proportion of the variance of the effect sizes in question. Lastly, meta-analytic methods allow for an accurate estimate of effect sizes across the various studies and is able to do so by weighting each source study appropriately (Cheung & Vijayakumar, 2016). These methods can also provide confidence intervals that offer important information regarding the precision with which these effect sizes have been measured in the literature, and to what degree these results can be interpreted (Borenstein, Hedges, Higgins, & Rothstein, 2009). These aims cannot be accomplished by individual source studies, or narrative or systematic reviews alone.

After examining the strengths of meta-analytic methods, there is important information that can be provided by meta-analysis regarding social outcome following pediatric TBI. The magnitude of the effects and the confidence intervals offer information regarding the degree to which children experience poor social outcome following TBI assessed by injury severity. We can also examine the effects that sample characteristics, such as injury severity, SES, age at injury, and time since injury have on the effect sizes and can determine the degree to which these sample characteristics moderate social outcome following pediatric TBI. No other method can address these questions. Given that social outcome is thought to be poor following pediatric TBI, and considering the scarcity of source studies examining sample characteristics as moderators of social outcome, meta-analytic methods can address these questions with increased statistical power (Rosema et al., 2012; Yeates et al., 2007).

Specific Aims and Hypotheses

Aim 1

The first aim of this meta-analysis was to determine the overall effect size of broad measures of psychosocial functioning in children with TBI compared to typically developing peers by injury severity group.

Hypothesis 1

A significant, detectable dose-response effect was expected in psychosocial functioning in relation to injury severity. More specifically, children with mild TBI were expected to exhibit small effect sizes, while those with moderate injuries were expected to exhibit small to medium effect sizes, and those with severe injuries were expected to exhibit medium to large effect sizes on these measures.

Aim 2

My second aim was to determine the effect size of specific social competence measures in children with pediatric TBI. Similar to the prior aim, these were calculated by injury severity group.

Hypothesis 2

Similar to the first hypothesis, a significant and detectable difference was expected in measures of social competence between injury severity groups. Children with mild TBI were expected to show small effect sizes, while children with moderate and severe TBI were expected to show small to medium, and medium to large effect sizes, respectively.

Aim 3

The third aim was to determine the relationship between social outcome following pediatric brain injury and SES. Specifically, to determine whether SES moderated social

competence and psychosocial functioning following pediatric TBI, and whether or not the variance in effect size between studies varied in a linear manner with the variability in SES between studies.

Hypothesis 3

SES was expected to be a significant moderator of parent report measures of social competence and psychosocial functioning following pediatric brain injury.

Aim 4

To determine the effects of age and time since injury on social competence and psychosocial functioning effect sizes following pediatric brain injury. Specifically, to examine whether age at injury moderated social competence and psychosocial functioning following pediatric brain injury and whether the variance in social competence and psychosocial functioning effect sizes was able to be predicted by age at injury. Also, I examined the relationship between time since injury and social competence and the interaction between age at injury and time since injury, and determine whether these variables were predictive of social competence.

Hypothesis 4

Age at injury would act as a significant moderator of parent reported measures of social competence and psychosocial functioning, and would indicate that younger ages of injury lead to greater impairment in social competence and psychosocial functioning following pediatric TBI. The interaction between age at injury and time since injury would also be a significant moderator of parent reported measures of social competence and psychosocial functioning, and would indicate that the greater the length of time since injury, the greater the impairment in social outcome.

Methods

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines were used (Moher, Liberati, Tetzlaff, & Altman, 2009). Likewise, the Quality Assessment of Diagnostic Accuracy Studies -2 (QUADAS-2) guidelines were used to assess the quality of studies included in this meta-analysis. These guidelines allowed for the assessment of study quality by two domains: risk of bias, and applicability/generalizability. These two domains were rated as either high risk, low risk, or unclear (Whiting et al., 2011).

Identification and Selection of Source Studies

Rosema et al., (2012) was hand searched for relevant articles and then the electronic databases (1) PubMed, (2) PsychInfo, and (3) Web of Science were searched for relevant articles. A search was conducted to find articles relating to pediatric TBI and social outcome using the search terms “(TBI OR head injury OR brain injury) AND (pediatrics OR children OR adolescents) AND (outcome OR changes OR social OR social cognition OR social adjustment OR social competence OR social function OR social interaction OR social skills OR psychiatric OR personality OR psychosocial OR adaptive OR behavior OR neurobehavioral OR symptomatology) NOT (Adults)”.

Inclusion Criteria

Peer reviewed articles published through February 2018 were considered for inclusion. A lower limit was not set on the date of publication. Studies must have been published in a peer reviewed journal, were to be written in English, and conducted at academic institutions. All studies must have contained data that could be converted into effect sizes, including means and standard deviations (or standard errors), correlation coefficients, *t* or *Z* values, or *F* ratios in order to compare social outcome between groups. Studies including children from ages of 1-17 years

and containing a control group were included in the analyses. Only children with accidental brain injury were considered. Finally, only studies including validated questionnaire measures of social outcome and psychosocial functioning were included in the analyses.

Data Extraction

After identifying studies that met the inclusion criteria described above, two trained members of the research group independently extracted relevant data including author names and publication year, sample size, statistical results related to measures of social outcome including (1) means and standard deviations (or standard errors), (2) correlation coefficients, (3) *t* or *Z* values, (4) *F* ratios, or (5) regression coefficients. Glasgow coma scale (GCS) scores, age at testing, age at injury, and SES were also extracted from source studies. Due to heterogeneity in how SES was reported across studies, the SES metric was standardized across studies by calculating an SES effect size for each sample.

Knowing that in the literature there exists multiple journal articles that utilize the same sample, it was decided that the article that presents the most recent available data *and* the appropriate standardized social outcome questionnaires were to be used. In two cases, separate articles used the same sample but they both reported recent and meaningful/usable data. In order to utilize the data to obtain the most comprehensive effect size estimates, both studies were included. However, the data was combined and analyzed as if it were a single study and sample so as to avoid violating the assumption of independence. Ganesalingam et al. (2011), Karver et al. (2012), and Karver et al. (2014) used the same sample, but each study provided different, relevant social competence and broad psychosocial data. These three studies were analyzed as a single study and sample. Anderson et al. (2017) and Ryan et al. (2016) also utilized the same

sample. These were treated in a similar manner as the studies described above and analyzed as a single study and sample to avoid violating assumptions of independence.

Using the QUADAS-2 tool described above, each study's QUADAS-2 score was coded (Whiting et al., 2011). Where possible, additional variables were extracted and used in the analyses. These variables related to characteristics of the developmental environment and included the type of healthcare system (universal health care or not), population density, and a metric of environmental poverty. Unemployment was used as a metric of poverty because it was one metric that could be accessed from several international census databases. Previous research has demonstrated a strong relationship between unemployment and poverty, and unemployment has often been considered a valid metric of poverty (Gallie, Paugam, & Jacobs, 2003; Hooghe, Vanhoutte, Hardyns, & Bircan, 2010). Developmental environment data was collected from online, official census bureau databases.

Group Categorization by Injury Severity

Groups were categorized using the average GCS score for the group provided in the article. As outlined by Teasdale and Jennett (1974), average GCS scores of 3-8 were considered *severe*, scores from 9-12 were considered *moderate*, and scores ranging from 13-15 were considered *mild*. These groupings of injury severity are consistent with a majority of articles included in the peer-reviewed literature relating to pediatric TBI. Studies relating to mild TBI (not including sports-related concussion) without GCS, but confirmed that there was a history of head injury with no loss of consciousness were also included.

Statistical Analysis and Data Synthesis

Comprehensive Meta-Analysis version 3.0 (Biostat, Englewood, NJ) was used to calculate effect sizes, homogeneity statistics, and meta-regressions.

Aim 1. In order to address aim one of this meta-analysis, which was to determine the overall effect size of broad measures of psychosocial functioning in children with TBI compared to typically developing peers, a summary Hedges's g effect size for broad psychosocial functioning was calculated using a random-effects model from each individual source study. Effect sizes were obtained for each severity group (mild, moderate, and severe) and Q and I^2 tests were conducted to determine whether there were significant differences in effect sizes between severity groups. Rosenthal's fail-safe N and funnel plot analyses were used to determine whether publication bias was present.

Aim 2. In order to address aim two of this meta-analysis, which was to determine the effect size of social competence measures in children with pediatric TBI when compared to typically developing peers or orthopedic injury groups, a summary Hedges's g effect size for social competence was calculated using a random-effects model from each individual source study. Effect sizes were obtained for each severity group (mild, moderate, and severe) and Q and I^2 tests were conducted to determine whether significant differences in effect sizes existed between severity groups. Rosenthal's fail-safe N and funnel plot analyses were used to determine whether publication bias was present.

Aims 3 and 4. As stated above, the third aim of this meta-analysis is to determine whether SES and developmental environment factors (unemployment, population density, and healthcare system) moderated social competence and psychosocial functioning following pediatric TBI. The fourth aim is to determine whether age at injury, time post-injury, and an interaction between the two moderated social competence and psychosocial functioning following TBI. In order to address these aims, meta-regression analyses were completed for both outcomes separately (broad psychosocial functioning and social competence). The effect size for

psychosocial functioning served as the dependent variable in a series of meta-regressions, and the effect size for social competence as the dependent variable in another series of meta-regressions. A meta-regression for both outcomes was completed with GCS to determine if injury severity was a significant moderator of effect size. GCS was also used as a covariate in all other meta-regressions in order to control for injury severity. This was particularly important because GCS has often been associated with other demographic variables (Nguyen et al., 2016; Roebuck-Spencer & Cernich, 2014). Time related variables (age at injury, time post-injury, and an interaction between the two) were entered into a regression analysis while controlling for injury severity. Next, SES and developmental environment factors (unemployment, population density, and healthcare system) were entered into meta-regression analyses while controlling for injury severity. Gender was entered into a regression analysis while controlling for injury severity. Finally, the type of control group that was used was entered into a final regression analysis after controlling for injury severity.

Results

Search Results

We reviewed the titles and abstracts of articles potentially meeting inclusion criteria based on search terms resulting in 17,837 full articles for further review of titles and abstracts (Rosema et al., (2012) = 28, PubMed = 8,288, PsycInfo = 2,994, Web of Science = 6,527). We retrieved full reports from 126 studies (Rosema et al., 2012 = 28, PubMed = 35, PsycInfo = 27, Web of Science = 36). This resulted in 16 studies that met inclusion criteria (Rosema et al., 2012 = 3, PubMed = 12, PsycInfo = 1, Web of Science = 0). Systematic search methods and results can be found in Figure 2.

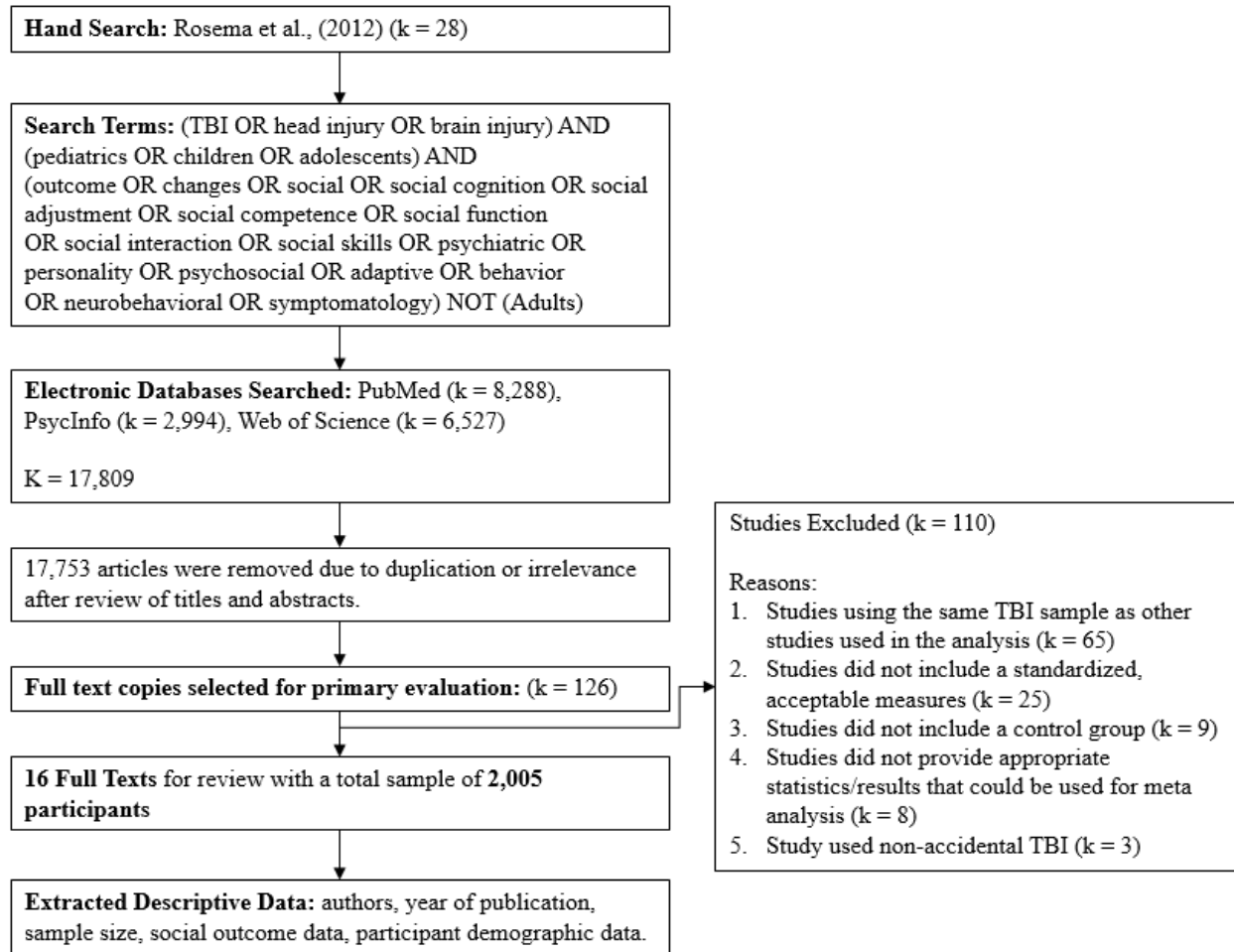


Figure 2. Flow diagram outlining systematic search method and the results of the systematic search.

Demographic Results

The total sample from these 16 studies consisted of 2,005 participants. Of these participants, 849 had a history of TBI, and 1,156 were controls. Age at injury ranged from age one to 13 years with an average age at injury of 7.24 years (SD = 3.71). Age at testing ranged from age two to 15 with an average age at testing of 9.68 years (SD = 4.01). The time interval between injury and testing ranged between 1.5 months post injury and 10 years post injury with an average interval time of 1.80 years (SD = 3.08). Females made up 37.87% of the sample. Demographic variables for each injury severity group can be found in Table 2. Individual study

information relating to sample size, mean GCS scores, and severity groups included can be found in Table 3. Measures of social competence and broad psychosocial functioning that were used for each study can be found in Table 4.

Table 2
Demographic Data Separated By Group

| Demographic | Mild | Moderate | Severe | Control |
|---|--------------|---------------------------|--------------|-------------|
| Group N | 501 | 185 | 163 | 1,156 |
| Age at Testing (Years) | 9.23 (4.03) | 9.15 (4.49) | 11.58 (3.61) | 8.75 (4.04) |
| Age at Injury (Years) | 6.77 (4.03) | 6.62 (3.16) | 9.30 (3.60) | - |
| Interval between Injury and Testing (Years) | 1.41 (2.72) | 2.54 (3.91) | 2.26 (3.31) | - |
| Percent Female | 38.29% | 38.94 % | 35.51% | 43.99% |
| GCS | 14.33 (0.54) | 11.94 [‡] (1.75) | 5.51 (1.43) | - |
| SES <i>Effect Size</i> * | -0.08 | -0.73 | -0.49 | † |

Note. Mean (SD); GCS = Glasgow Coma Scale; SES = Socioeconomic Status;

*Lower effect sizes indicate lower SES. Hedges's *g* was calculated in order to standardize effect sizes across studies. †Could not calculate SES effect size for the control group because the control group was used as the reference group in order to calculate the SES effect sizes for the TBI groups. ‡The mean GCS for the moderate group was near 12 because in many studies, the moderate consisted of moderate TBI (GCS of 9-12) combined with mild-complicated TBI, consequently inflating the mean GCS.

Table 3

Sample Size, Severity Definitions, And Control Group Utilized For Each Source Study

| Article | Mild N (GCS) | Moderate N (GCS) | Severe N (GCS) | Control N (Controls) |
|--|--------------------|------------------------|----------------------|----------------------------|
| Anderson et al., 2012 ^ϕ | 7 (13.57) | 20 (10.85) | 13 (5.69) | 16 (TD) |
| Anderson et al., 2017 | 38 (14.53) | 36 (11.00) | | 40 (TD) |
| Bellerose et al., 2017 | 72 (14.89) | | | 83 (OI) |
| Crowe et al., 2012 | 19 (14.40) | 15 (9.2) | | 18 (TD) |
| Ganesalingam et al., 2011 [‡] | 64 (13.45) | | 23 (3.83) | 119 (OI) |
| Kaldoja et al., 2014 | 27 (GCS 13-15) | | | 54 (TD) |
| Karver et al., 2012 [‡] | 63 (13.45) | | 23 (3.83) | 117 (OI) |
| Karver et al., 2014 [‡] | 47 (13.39) | | 18 (3.94) | 74 (OI) |
| Levin et al., 2009 | | | 52 (7.44) | 41 (OI) |
| Liu et al., 2013 | 97 (No LOC) | | | 558 (TD) |
| Max et al., 1998 | 24 (14.50) | | 24 (5.29) | 24 (OI) |
| Micklewright et al., 2012 | | | 21 (4.00) | 23 (OI) |
| Ryan et al., 2016 ^ϕ | 47 (14.38) | 20 (11.43) | 11 (6.55) | 40 (TD) |
| Shultz et al., 2016 | | 50 (GCS 9-12) | 19 (GCS ≤ 8) | 60 (OI) |
| Studer et al., 2014 | 33 (14.78) | | | 32 (OI) |
| Taylor et al., 2015 | 176 (GCS 13-15) | | | 90 (OI) |

^ϕThese two articles used the same sample but reported different measures. Consequently, both were used. [‡]These three articles used the same sample but reported different measures. Consequently, both were used. GCS = Glasgow Coma Scale; LOC = Loss of Consciousness; OI = Orthopedic Injury; TD = Typical Development

Table 4

A Comprehensive List Of The Measures That Were Used To Assess Social Competence And Broad Psychosocial Functioning And Their Study Source

| Article | Social Competence | Broad Psychosocial Functioning |
|---------------------------|---|---|
| Anderson et al., 2012 | ABAS-II Social Composite | ABAS-II Total Composite |
| Anderson et al., 2017 | ABAS-II Social Scale | ABAS-II Total Composite, CBCL Total Problems |
| Bellerose et al., 2017 | ABAS Social Scale | ABAS Total Composite |
| Crowe et al., 2012 | SSRS Total | CBCL Total Problems |
| Ganesalingam et al., 2011 | ABAS Social Scale | — |
| Kaldoja et al., 2014 | — | ASQ:SE Total Score |
| Karver et al., 2012 | PKBS-2/HCSBS Social Skills Scale | — |
| Karver et al., 2014 | — | CBCL Total |
| Levin et al., 2009 | VABS Socialization Scale | — |
| Liu et al., 2013 | — | CBCL Total |
| Max et al., 1998 | CBCL Social Problems, VABS Socialization | VABS Total |
| Micklewright et al., 2012 | — | VABS Total |
| Ryan et al., 2016 | CBCL Social Problems | — |
| Shultz et al., 2016 | ABAS-II Social, BASC-2 Social Skills | ABAS-II Total |
| Studer et al., 2014 | SDQ Social/Peer Problems | — |
| Taylor et al., 2015 | CBCL Social Problems | CBCL Total |

Note. ABAS = Adaptive Behavior Assessment System; ABAS-II = Adaptive Behavior Assessment System – Second Edition; ASC:SE = Ages and Stages Questionnaire: Social-Emotional; BASC-2 = Behavior Assessment System for Children – Second Edition; CBCL = Child Behavior Checklist; HCSBS = Home and Community Social and Behavior Scales; PKBS-2 = Preschool and Kindergarten Behavior Scales – Second Edition; SDQ = Strengths and Difficulties Questionnaire; SSRS = Social Skills Rating Scale; VABS = Vineland Adaptive Behavior Scale.

QUADAS-2 Ratings

Results of the QUADAS-2 ratings indicated that one study (Liu & Li, 2013) demonstrated bias in patient selection procedures. All studies but one demonstrated high risk of bias in their index test procedures. Two studies demonstrated high risk of bias in their procedures related to the reference standard. Five studies were considered to be at high risk of bias in relation to their flow and timing. Four studies had low concern for applicability and generalizability, while 11 studies showed moderate concern for applicability, and one study demonstrated high concern for applicability.

Table 5

Results Of The QUADAS-2 Ratings For Each Source Study And Their Risk Of Bias And Concerns For Applicability And Generalizability

| Study | Risk of Bias | | | | Applicability Concerns | | |
|---------------------------|-------------------|------------|--------------------|-----------------|------------------------|------------|--------------------|
| | Patient Selection | Index Test | Reference Standard | Flow and Timing | Patient Selection | Index Test | Reference Standard |
| Anderson et al., 2012 | Low | High | Low | High | Low | Low | Low |
| Anderson et al., 2017 | Low | High | Low | Low | Low | High | Low |
| Bellerose et al., 2017 | Low | High | Low | Low | High | Low | Low |
| Crowe et al., 2012 | Low | High | Low | Low | High | Low | Low |
| Ganesalingam et al., 2011 | Low | High | Low | Low | High | High | Low |
| Kaldoja et al., 2014 | Low | High | Low | High | High | Low | Low |
| Karver et al., 2012 | Low | High | Low | High | High | High | Low |
| Karver et al., 2014 | Low | High | Low | High | High | High | Low |
| Levin et al., 2009 | Low | High | Low | Low | Low | High | Low |
| Liu et al., 2013 | High | Low | High | Low | High | High | High |
| Max et al., 1998 | Low | High | Low | Low | Low | Low | Low |
| Micklewright et al., 2012 | Low | High | Low | Low | Low | Low | High |
| Ryan et al., 2016 | Low | High | Low | Low | Low | Low | Low |
| Shultz et al., 2016 | Low | High | Low | Low | Low | Low | High |
| Studer et al., 2014 | Low | High | Low | High | Low | Low | Low |
| Taylor et al., 2015 | Low | High | High | Low | Low | High | High |

Broad Psychosocial Measures

Mild TBI. Parent report measures of broad psychosocial functioning for children with mild TBI had a small to medium effect size of -0.387, 95% CI [-0.734, -0.040]; $p = 0.029$ (Figure 3). The CI for these measures in mild TBI was relatively large, indicating a broad range for the true effect size. A Q -test analysis demonstrated that there was significant heterogeneity in effect sizes between studies, $Q = 57.673$; $p < 0.01$. An I^2 analysis revealed a large amount of between-study heterogeneity, $I^2 = 86.129$.

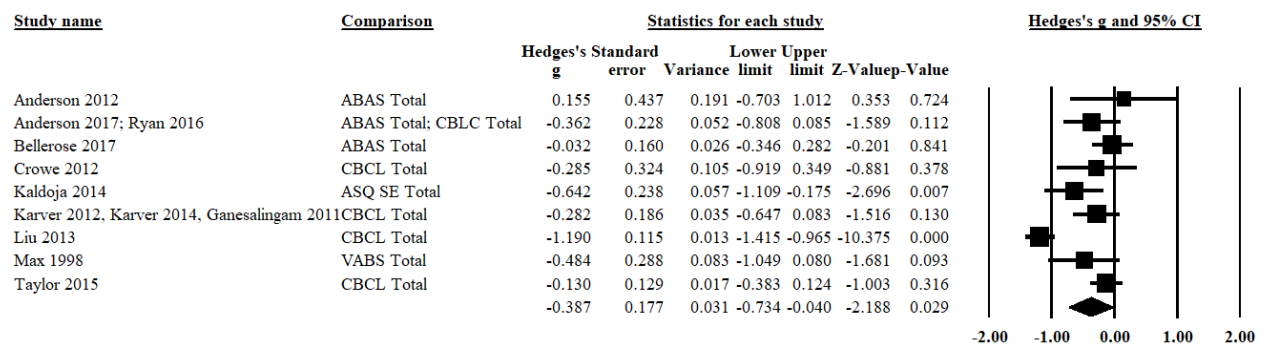


Figure 3. Forest plot for effect sizes of broad psychosocial function for the mild TBI group.

The funnel plot for measures of broad psychosocial functioning in children with mild TBI demonstrated little evidence for publication bias, as there were no studies with large standard errors and large effect sizes, and most studies fell well within the funnel (see Figure 4). Rosenthal’s fail-safe N indicated that 91 studies with non-significant results would be needed to bring p value for the overall effect size to above 0.05.

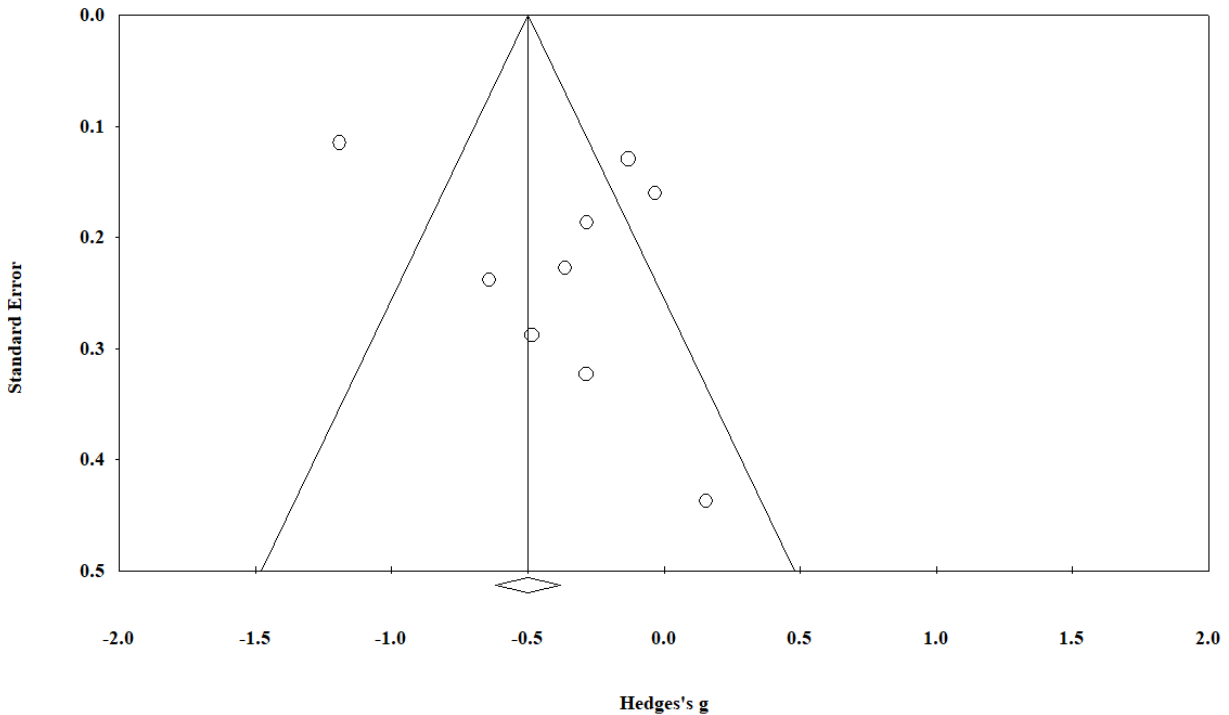


Figure 4. Funnel plot for broad psychosocial function in children with mild TBI.

Moderate TBI. Parent report measures of broad psychosocial functioning for children with moderate TBI had a small, non-significant effect size of -0.257 , 95% CI $[-0.678, 0.167]$; $p = 0.231$ (Figure 5). The CI for these measures in moderate TBI was large, indicating a broad range for the true effect size. A Q -test analysis demonstrated that there was significant heterogeneity in effect sizes between studies, $Q = 7.827$; $p = 0.050$. An I^2 analysis revealed medium between-study heterogeneity, $I^2 = 61.671$. Three of the four studies appeared to be relatively homogenous, with Shultz et al. (2016) appearing as a possible outlier. A re-analysis of effect sizes with Shultz et al. (2016) removed revealed that the effect size of broad psychosocial function for children with moderate TBI was medium and statistically significant -0.459 , 95% CI $[-0.786, -0.132]$; $p = 0.006$ (Figure 6). Confidence intervals continued to be large, indicating a broad range for the true effect size. Importantly, a Q -test demonstrated that the removal of Shultz et al., 2016 from the analysis created homogeneity between studies, $Q = 0.754$, $p = 0.686$, $I^2 = 0.00$.

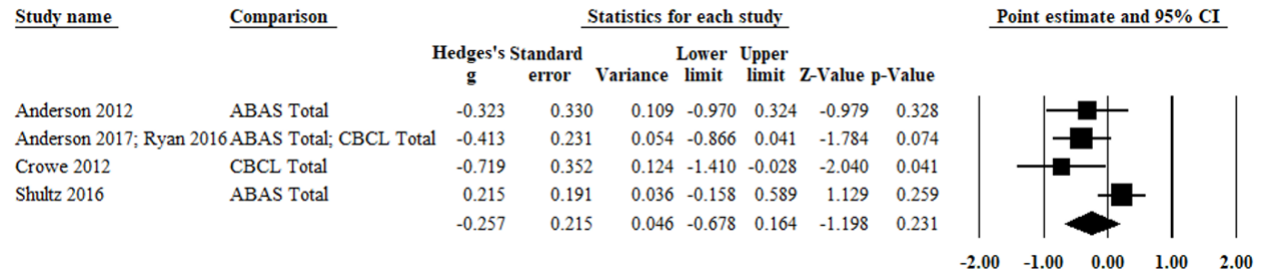


Figure 5. Forest plot for effect sizes of broad psychosocial function for the moderate TBI group.

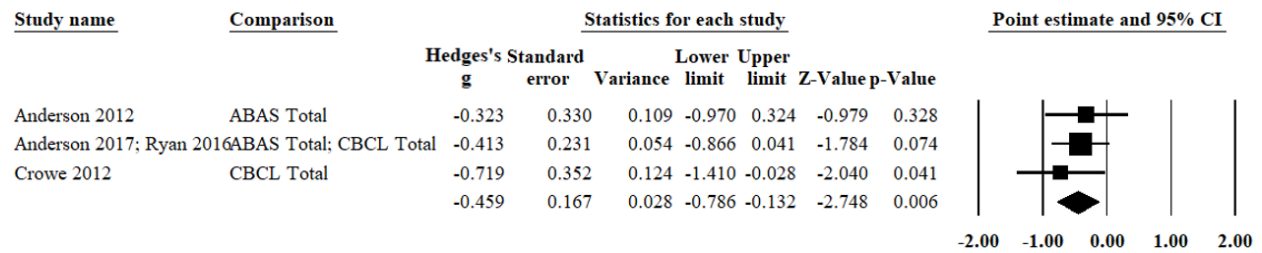


Figure 6. Forest plot for effect sizes of broad psychosocial function for the moderate TBI group with Shultz et al. (2016) removed.

The funnel plot for measures of broad psychosocial functioning in children with moderate TBI demonstrated little evidence for publication bias, as there were no studies with large standard errors and large effect sizes, and all studies fell well within the funnel (see Figure 7).

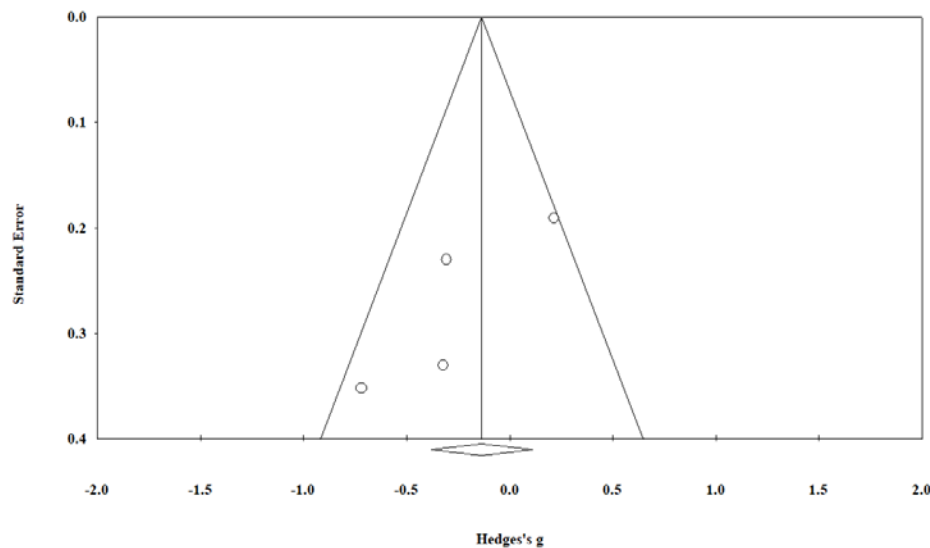


Figure 7. Funnel plot for broad psychosocial function in children with moderate TBI.

Severe TBI. Parent report measures of broad psychosocial functioning for children with severe TBI had a large, significant effect size of -0.814, 95% CI [-1.075, -0.554]; $p < 0.001$ (Figure 8). The CI for these measures in severe TBI was relatively large, indicating a broad range for the true effect size. A Q -test analysis demonstrated that there was not significant heterogeneity in effect sizes between studies, $Q = 0.648$; $p = 0.958$. An I^2 analysis revealed no between-study heterogeneity exists, suggesting homogeneity, $I^2 = 0.00$.

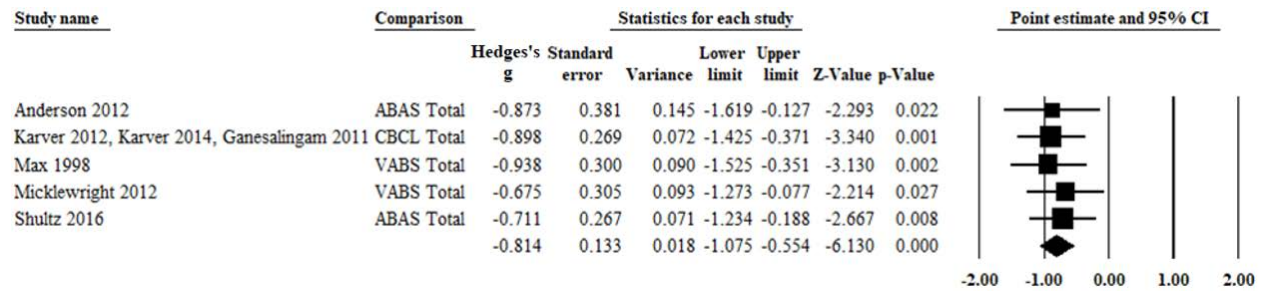


Figure 8. Forest plot for effect sizes of broad psychosocial function for the severe TBI group.

The funnel plot for measures of broad psychosocial functioning in children with severe TBI demonstrated little evidence for publication bias, as there were no studies with large standard errors and large effect sizes, and all studies fell well within the funnel (see Figure 9). Rosenthal’s fail-safe N indicated that 44 studies with non-significant results would be needed to bring p value for the overall effect size to above 0.05.

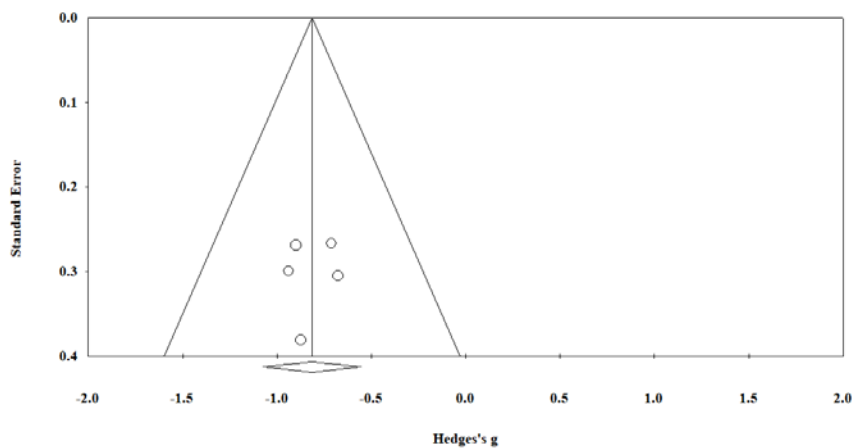


Figure 9. Funnel plot for broad psychosocial function in children with severe TBI.

Differences between severity groups. A Q -test analysis demonstrated that there was a significant difference in effect sizes between severity groups, $Q = 6.446$; $p = 0.040$. An I^2 analysis revealed a medium to large degree of heterogeneity exists between severity groups on measures of broad psychosocial functioning, $I^2 = 68.973$.

Moderating variables of broad psychosocial effect sizes. A meta-regression analysis that examined GCS as a moderator between effect sizes of broad psychosocial function was significant, $B = 0.065$, $p < 0.001$, such that lower GCS was associated with poorer psychosocial outcome. (Figure 10).

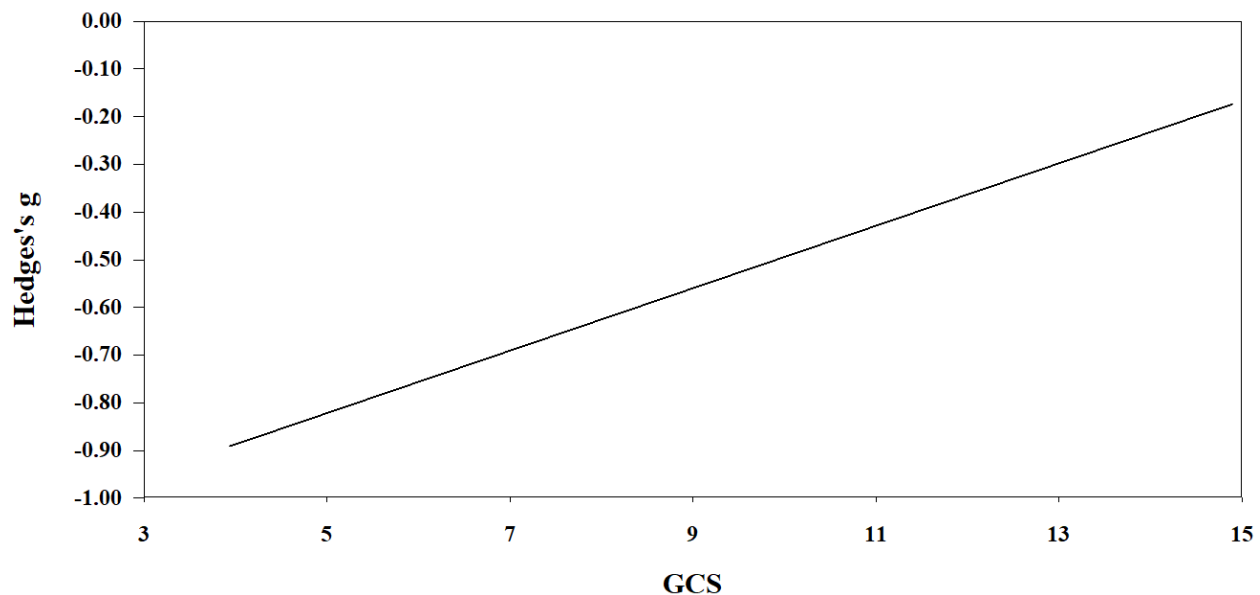


Figure 10. Regression of GCS on effect size of broad psychosocial function.

Note: GCS = Glasgow Coma Scale Scores

Time related variables, including age at injury, $B = -0.064$, $p = 0.52$, time since injury, $B = -0.113$, $p = 0.59$, and an interaction between age at injury and time since injury, $B = 0.025$, $p = 0.56$, were not significant moderators of effect size of broad psychosocial function. After controlling for injury severity, SES was not a significant moderator between effect sizes of broad psychosocial function, $B = -0.184$, $p = 0.35$. After controlling for injury severity, developmental

environment factors, including poverty (as measured by unemployment), $B = 0.024$, $p = 0.51$, population density, $B = 0.0001$, $p = 0.63$, and access to universal healthcare, $B = 0.0814$, $p = 0.62$, were not significant moderators of effect size of broad psychosocial function. Finally, post-hoc analyses revealed that even after controlling for injury severity, gender was a significant moderator of effect size of broad psychosocial function, such that studies with higher proportion of females exhibited lower effect sizes on measures of broad psychosocial function $B = 0.018$, $p = 0.05$ (Figure 11). The type of control group used (TD versus OI) was not a significant moderator of effect size of broad psychosocial function, $B = -0.814$, $p = 0.62$.

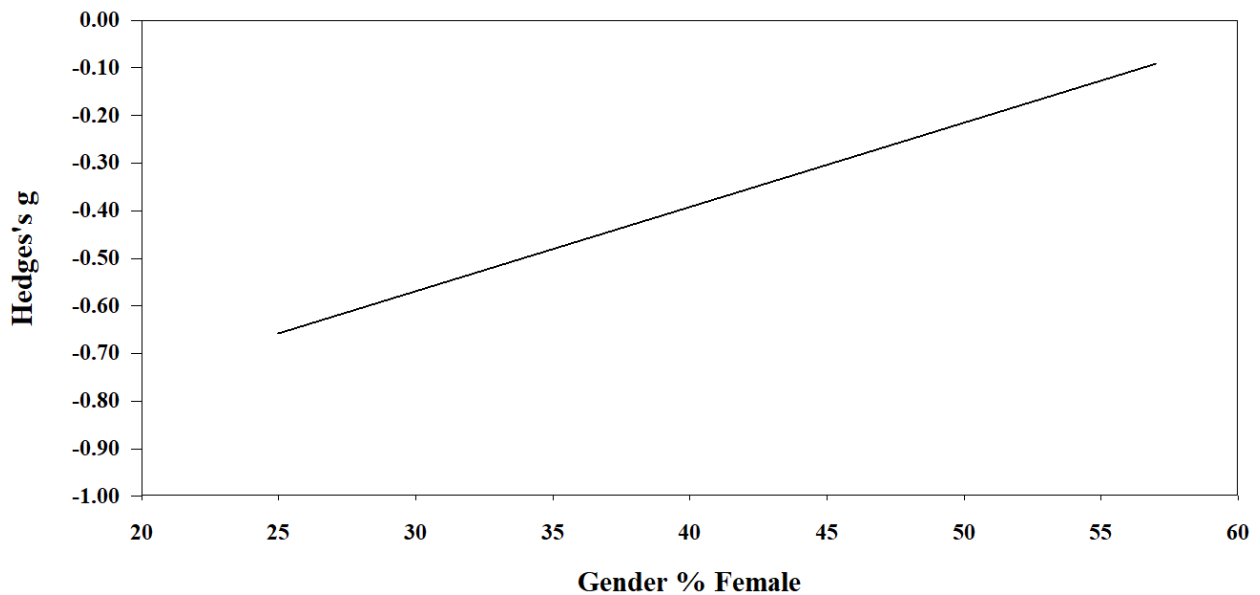


Figure 11. Regression of gender (% female) on effect size of broad psychosocial function.

Social Competence Measures

Mild TBI. Parent report measures of social competence for children with mild TBI has a small, non-significant effect size of -0.098 , 95% CI $[-0.260, 0.065]$; $p = 0.239$ (Figure 12). The CI for these measures in mild TBI was relatively large, indicating a broad range for the true effect size. A Q -test analysis demonstrated that there was not significant heterogeneity in effect

sizes between studies, $Q = 8.793$; $p = 0.268$. An I^2 analysis revealed a small amount of between-study heterogeneity, $I^2 = 20.388$.

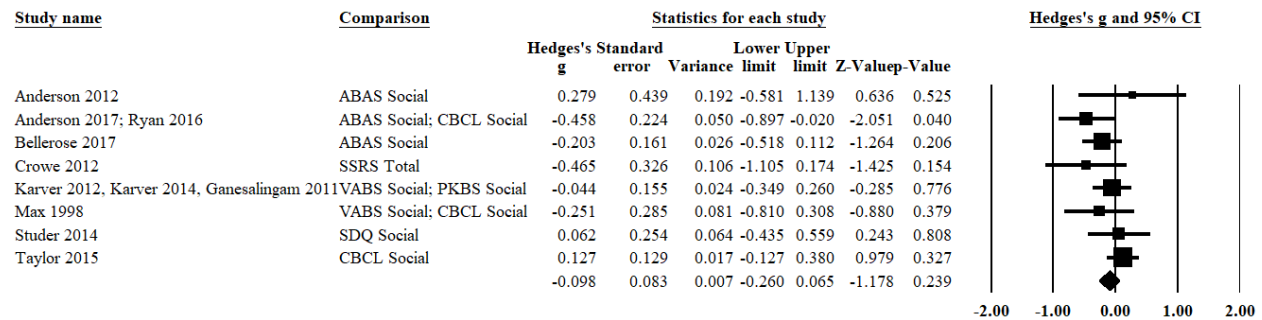


Figure 12. Forest plot for effect sizes of social competence for the mild TBI group.

The funnel plot for measures of social competence in children with mild TBI demonstrated little evidence for publication bias, as there were no studies with large standard errors and large effect sizes, and all studies fell within the funnel (Figure 13).

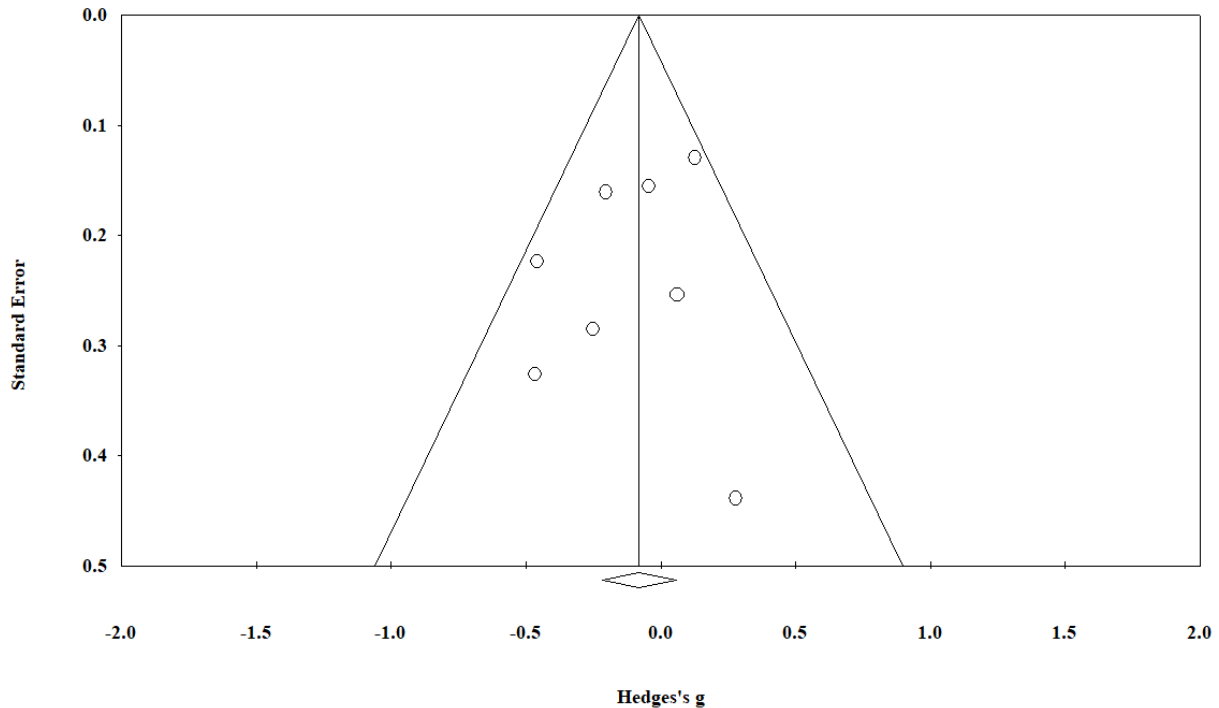


Figure 13. Funnel plot for effect sizes of social competence for the mild TBI group.

Moderate TBI. Parent report measures of social competence for children with moderate TBI had a small, non-significant effect size of -0.230, 95% CI [-0.618, 0.158]; $p = 0.245$ (Figure 14). The CI for these measures in moderate TBI was large, indicating a broad range for the true effect size. A Q -test analysis demonstrated that there was not significant heterogeneity in effect sizes of social competence between studies, $Q = 6.394$, $p = 0.094$. An I^2 analysis revealed medium between-study heterogeneity, $I^2 = 53.083$. Three of the four studies appeared to be relatively homogenous, with Shultz et al. (2016) appearing as a possible outlier. A re-analysis of effect sizes with Shultz et al. (2016) removed revealed that the effect size of social competence for children with moderate TBI was medium and statistically significant -0.450, 95% CI [-0.792, -0.108]; $p = 0.01$ (Figure 15). Confidence intervals continued to be large, indicating a broad range for the true effect size. Importantly, a Q -test demonstrated that the removal of Shultz et al. (2016) from the analysis created homogeneity between studies, $Q = 0.377$, $p = 0.828$, $I^2 = 0.00$.

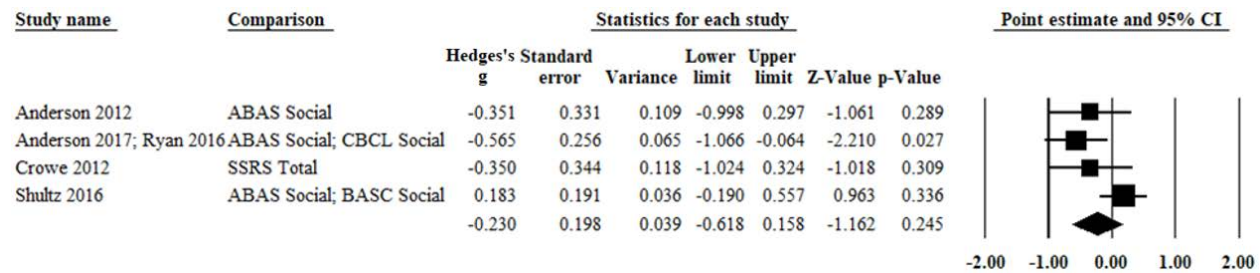


Figure 14. Forest plot for effect sizes of social competence for the moderate TBI group.

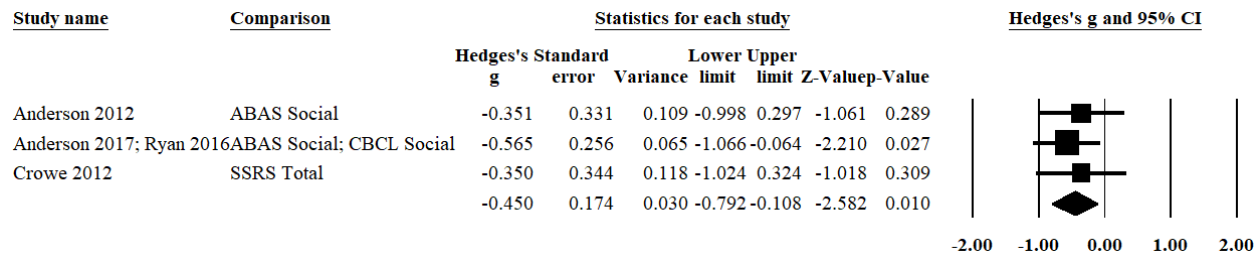


Figure 15. Forest plot for effect sizes of social competence for the moderate TBI group with Shultz et al. (2016) removed.

The funnel plot for measures of social competence in children with moderate TBI demonstrated little evidence for publication bias, as there were no studies with large standard errors and large effect sizes. All studies fell within the funnel (Figure 16).

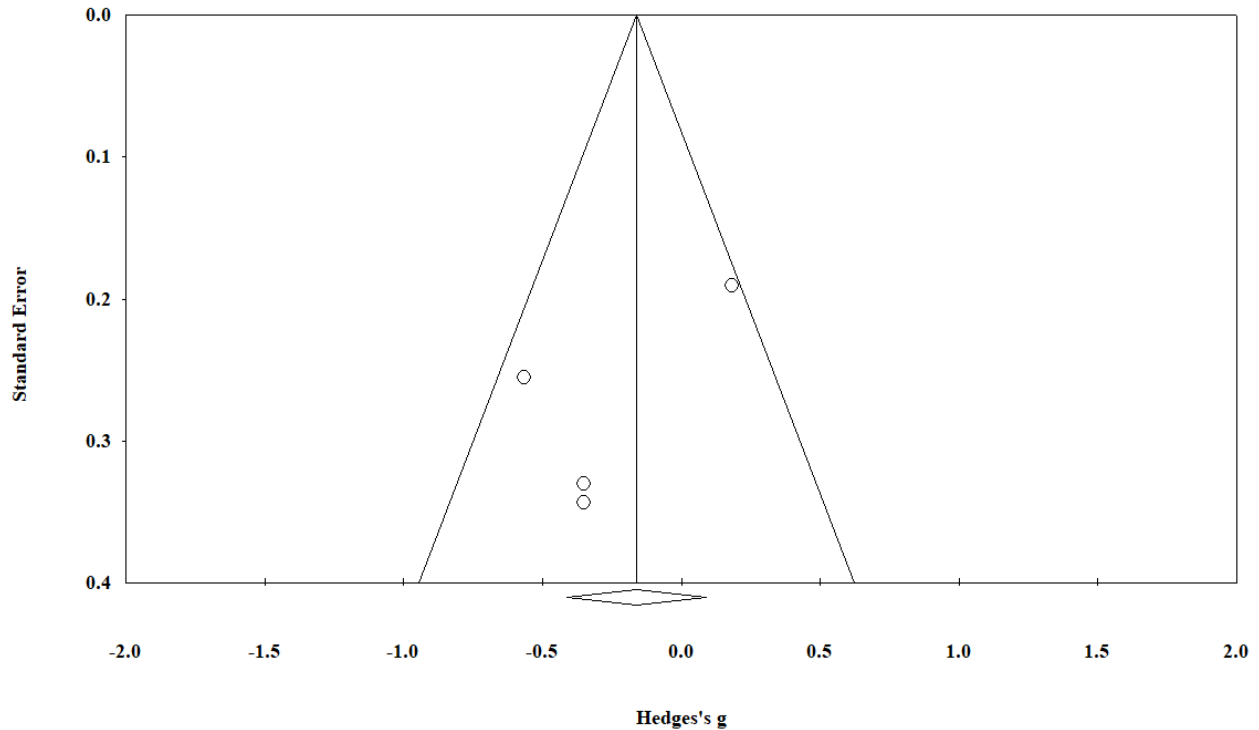


Figure 16. Funnel plot for effect sizes of social competence for the moderate TBI group.

Severe TBI. Parent report measures of social competence for children with severe TBI had a large, significant effect size of -0.832 , 95% CI $[-1.19, -0.470]$, $p < 0.001$ (Figure 17). The CI for social competence in severe TBI was large, indicating a broad range for the true effect size. A Q -test analysis revealed that there was significant heterogeneity in effect sizes between studies, $Q = 0.12.783$; $p = 0.025$. An I^2 analysis revealed that a medium amount of between-study heterogeneity exists, $I^2 = 60.886$.

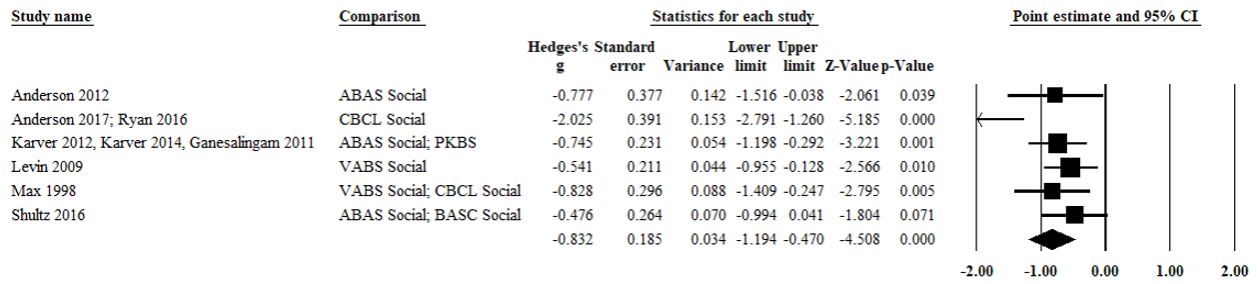


Figure 17. Forest plot for effect sizes of social competence for the severe TBI group.

The funnel plot for measures of social competence in children with severe TBI demonstrated that little evidence for overall publication bias, and all but one study fell within the funnel. However, one outlying study may indicate some publication bias as this study had a large standard error (indicating small sample size) and a very large effect size of ~2.0 (Figure 18). Rosenthal’s fail-safe N indicated that 75 studies with non-significant results would be needed to bring the *p* value for the overall effect size to above 0.05.

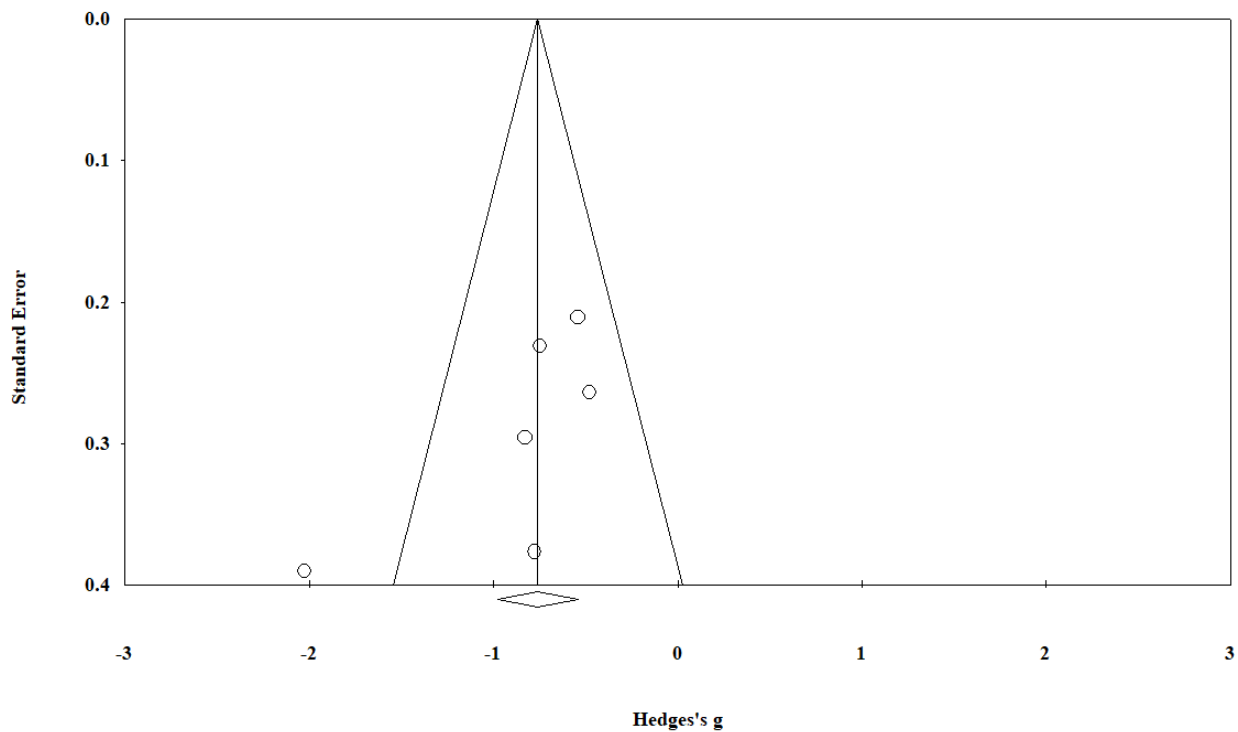


Figure 18. Funnel plot for effect sizes of social competence for the severe TBI group.

Difference between severity groups. A Q -test analysis demonstrated that there were significant differences in effect sizes between severity groups, $Q = 13.183$; $p = 0.001$. An I^2 analysis revealed a large degree of heterogeneity exists between severity groups on measures of social competence, $I^2 = 84.836$.

Moderating variables of social competence effect sizes. Meta-regression that examined GCS as a moderator of effect sizes of social competence was significant, $B = 0.079$, $p < 0.001$, such that lower GCS was association with poorer psychosocial outcome. (Figure 19).

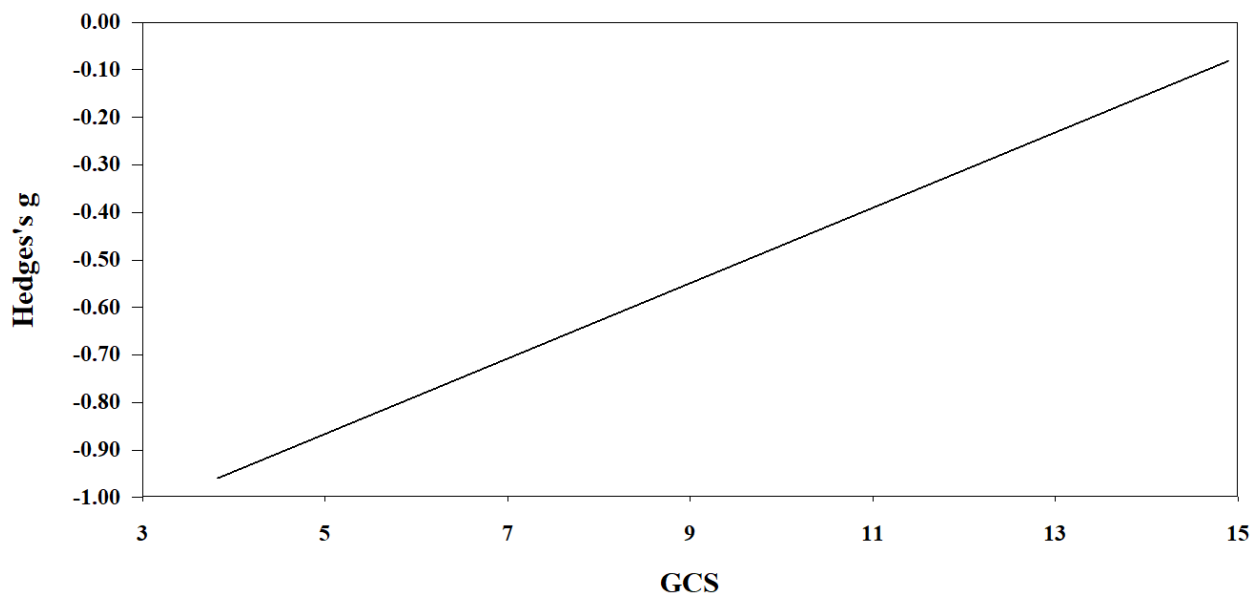


Figure 19. Regression of GCS on effect size of social competence.

Note. GCS = Glasgow Coma Scale Scores

After controlling for injury severity, time related variable, including age at injury, $B = 0.073$, $p = 0.22$, time since injury, $B = 0.201$, $p = 0.20$, and an interaction between age at injury and time since injury, $B = -0.033$, $p = 0.28$, were not significant moderators of effect size of social competence. After controlling for injury severity, SES was not a significant moderator of effect size between studies on measures of psychosocial function, $B = -0.255$, $p = 0.24$. After controlling for injury severity, developmental environment factors, including poverty (as

measured by unemployment), $B = 0.061$, $p = 0.35$, population density, $B = 0.0002$, $p = 0.19$, and access to universal healthcare, $B = -0.363$, $p = 0.26$, were not significant moderators of effect size between studies on measures of social competence. Finally, post-hoc analyses revealed that gender was not a significant moderator of effect size of social competence, $B = -0.002$, $p = 0.67$. The type of control group used (TD versus OI) was a significant moderator of effect size between studies on measures of social competence, $B = 0.369$, $p = 0.03$. Results indicated that studies that used an orthopedic injury group as the control group systematically had smaller effect sizes compared to studies that used typically developing control groups (Figure 20)

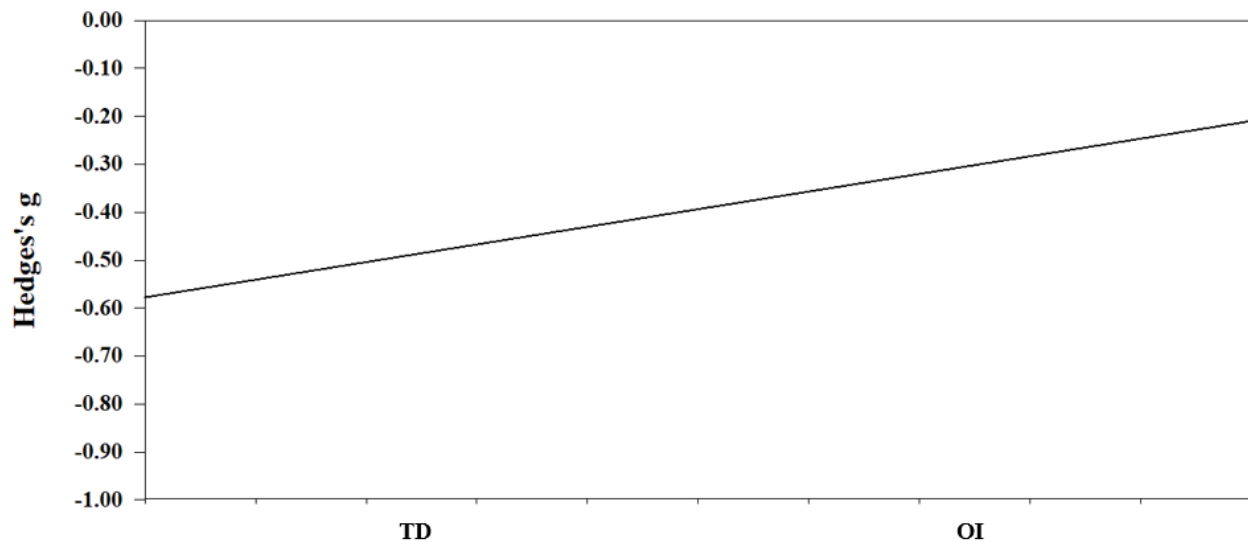


Figure 20. Regression of type of control group used on effect size of social competence.

Note. TD = Typically Developing Controls, OI = Orthopedic Injury Controls

Discussion

Literature and Study Characteristics

After close review of 126 studies examining social competence or broad psychosocial functioning following pediatric TBI, 16 studies met inclusion criteria and represented 13 samples of children and adolescents with TBI. Importantly, 65 of the studies used a same sample as one of the studies included in this analysis. As a result, most of what we have come to know and

understand about psychosocial functioning and social competence following TBI comes from a relatively small number of samples of children and adolescents with TBI.

In terms of the standardized measures that have been used to operationalize social competence and psychosocial function, there was some degree of homogeneity in the literature. Seven studies used the Child Behavior Checklist, five studies used the Adaptive Behavior Assessment System, and three studies used the Vineland Adaptive Behavior Scale. Although the measures that were used were not completely homogenous, these three measures represented a large proportion of the measures that have been used in the literature. Each of these measures are standardized, well accepted, and clinically useful. However, none of these measures was specifically developed for use in traumatic brain injury.

The QUADAS-2 ratings revealed important information regarding the risk of bias and applicability of the samples that make up our knowledge base regarding pediatric TBI and social outcomes generally (Whiting et al., 2011). Broadly, most studies did not introduce bias in their recruitment and selection. Although they were not able to avoid a case-control design due to the nature of TBI, they used consecutive enrollment methods and used appropriate exclusion criteria. High risk of bias was introduced in most studies because index test results were interpreted with the knowledge of the reference standard, which is the GCS. The index test in each case was the same as the reference standard (GCS). Consequently, these studies did not introduce bias related to the reference standard used because the reference standard (GCS) is likely to classify the target condition. Five studies demonstrated high risk of bias in relation to flow and timing, and in each of these samples, the risk was introduced as a result of significant participant dropout at extended follow up. Finally, applicability concerns in relation to patient selection were present in seven studies, and each of these were due to very limited age ranges, usually in toddlers. Finally,

applicability concerns were raised because of index tests and reference standards. Concerns regarding applicability were introduced when studies combined severity groups into a single group. This most often occurred when studies grouped moderate TBI with a complicated mild TBI group. By grouping these together, generalizability was reduced.

Broad Psychosocial Outcomes

In this meta-analysis we found that pediatric TBI was associated with poorer psychosocial functioning based on parent report measures. More specifically, even children with mild TBI demonstrated small effect sizes, and these effects were statistically significant when compared to controls. Children with moderate TBI demonstrated small, non-significant effect sizes. However, when one outlying study was removed, medium and statistically significant effect sizes were observed. Although Shultz et al. (2016) was observed to be as statistical outlier, there was nothing in its methodology that would suggest it be removed from the analyses. It is notable that only four studies examined moderate TBI, thus the moderate TBI group was likely underpowered. As a result, the overall effect size was considered non-significant. Finally, the severe TBI group had large and statistically significant effect size, indicating much poorer psychosocial function when compared to controls.

Heterogeneity analyses can also provide information related to the similarity of findings between studies. The mild and moderate TBI groups demonstrated significant heterogeneity, indicating significant differences in effect sizes between studies. This finding is consistent with the literature in psychosocial outcome in mild TBI. Previous research examining psychosocial function after mild TBI has yielded mixed results. Moderate TBI has largely shown medium effects, with the exception of a single study that yielded small, non-significant results. Interestingly, there was not significant heterogeneity between studies in the severe TBI group,

indicating that all studies examining psychosocial functioning in severe TBI found relatively large effects and poorer psychosocial functioning.

Social Competence Outcomes

Results of this meta-analysis also revealed that children with mild TBI did not experience significant negative effects in social competence, and the effects were small. Similar to the findings of psychosocial function, children with moderate TBI demonstrated small, non-significant effects in social competence. When one study was removed, a medium and significant effect was observed. However, Shultz et al. (2016) was not methodologically different than other studies and consequently should be included in the analyses and interpretation, despite being a statistical outlier. Children with a history of severe TBI demonstrated large, significant effect sizes and overall poorer social competence.

Further, heterogeneity analyses revealed information related to similarity in effect sizes between studies. In contrast to the findings in psychosocial function, the mild TBI group demonstrated small, non-significant heterogeneity between studies. This finding is somewhat unexpected because the literature seems to have yielded mixed results with studies demonstrating both significant and non-significant findings in relation to social competence. The moderate TBI group demonstrated medium between-study heterogeneity. And finally, there was also a medium amount of heterogeneity between study effect sizes in the severe group. Overall, our findings related to broad psychosocial outcome and social competence seem to fit with our current understanding of social outcome following pediatric TBI (Rosema et al., 2012). Similarly, the findings of our current meta-analysis are consistent with previous meta-analytic findings demonstrating poor neurocognitive, academic, and quality of life outcomes after pediatric TBI

(Babikian & Asarnow, 2009; Di Battista, Soo, Catroppa, & Anderson, 2012; Vu, Babikian, & Asarnow, 2011).

Injury Severity

In our series of meta-regressions, we found that injury severity as measured by the GCS was a very strong predictor of effect sizes for both broad psychosocial functioning and social competence after pediatric TBI. More specifically, higher GCS scores were associated with smaller effect sizes, while lower GCS scores were associated with larger effect sizes. Interpreted, children who sustained a mild TBI tended to have better psychosocial and social competence outcomes, while children with severe injuries had poorer psychosocial and social competence outcomes. This finding was also confirmed using *Q*-test analyses, and there were significant differences in effect sizes between severity groups, with the severe TBI group having the worst outcomes.

These findings are consistent with our knowledge regarding neurocognitive recovery after pediatric TBI. Previous meta-analyses have demonstrated that children who experience mild injuries also demonstrate small effect sizes, and they tend to recover and return to baseline functioning. Children with moderate and severe injuries had larger effect sizes in relation to neurocognitive outcome (Babikian & Asarnow, 2009). A similar pattern was found in quality of life following pediatric TBI (Di Battista et al., 2012). Consequently, it is not surprising that similar results were found in our meta-analysis given the significant relationships between neurocognitive outcome, quality of life and psychosocial and social competence. Evidence has continued to mount and support the notion that poor social competence following pediatric TBI is often mediated by other neurocognitive skills, including executive functions, attention, inhibitory control, self-monitoring, and cognitive control (Catroppa, Anderson, Godfrey, &

Rosenfeld, 2011; Ganesalingam et al., 2006; Levin et al., 2009; Wolfe et al., 2015). After consideration of surmountable evidence that children with more severe injuries have poorer outcome follow TBI, our findings are consistent with previous evidence, and suggest that children with severe TBI have poorer psychosocial outcomes when compared to children with mild injuries.

In our meta-analysis we found that the moderate group had a smaller effect size than the mild group on measures of broad psychosocial functioning. However, when one outlying study was removed, the moderate TBI group had a larger effect size than the mild TBI group. It is noteworthy that the moderate group only had four studies, and this specific group was likely underpowered and resulted in the inconsistent findings described.

Time Related Variables

A series of meta-regression analyses revealed that age at injury and time post injury, as well as an interaction between the two variables, were not significant moderators of psychosocial outcome or social competence from a meta-analytic perspective. This finding is relatively inconsistent with previous findings, although this specific research question has largely gone unstudied. To date, two known studies have explicitly tested this hypothesis, and both studies demonstrated that children with a younger age at injury had poorer outcomes (Rosema et al., 2012). However, a previous meta-analysis examining neurocognitive outcomes following pediatric TBI did not detect a significant effect for age at injury (Babikian & Asarnow, 2009)

Similar to age at injury, time since injury has a relatively small research base with mixed results. Studies that have found an effect have also reported that it is often mediated by other factors, including injury severity and the home environment (Anderson et al., 2006; Yeates et al., 2010). Similar to our findings in the current meta-analysis, a previous meta-analysis was also

unable to confirm that time post injury was a significant moderator of neurocognitive outcome after pediatric TBI (Babikian & Asarnow, 2009).

Socioeconomic Status and Developmental Environment

The results of the current meta-analysis revealed that SES was not a significant moderator of effect sizes between studies. Similarly, other developmental environment factors, including environmental poverty (as measured by unemployment), population density, and healthcare availability did not moderate effect sizes between studies. Previous research has consistently placed SES as a significant predictor of overall outcome following TBI (Taylor et al., 1999). Reasons for the null findings described are unclear. However, one possible reason for the discrepancy could be due to the small number of studies examining these associations. In their systematic review, Rosema et al. (2012) only identified two studies that had examined the relationship between SES and social outcomes. This association may not have been observed in the other studies used in this meta-analysis. The effects of developmental environment were also non-significant. However, there is virtually no previous research that examines specific environmental factors with the exception of SES. However, these other factors, including environmental poverty, population density (inner city versus rural), and access to healthcare are all important factors to be considered in future research.

Gender Effects

Similar to our findings in this meta-analysis, the research relating to gender differences in outcome following TBI is mixed. Our results indicated that studies with larger proportions of females systematically had smaller effect sizes. This finding suggests that females may have better psychosocial outcomes after traumatic brain injury. However, this finding was limited to broad psychosocial outcomes and was not replicated in our examination of social competence.

Farace and Alves (2000) examined gender outcomes following TBI in adults and concluded that women tend to fare worse following TBI. However, other studies have suggested that adult women tend to have better outcomes after TBI (Berry et al., 2009). Importantly, a meta-analysis conducted by Karr, Areshenkoff, and Garcia-Barrera (2014) suggested that most studies that find poorer outcomes for females are those that examine mild TBI only.

In pediatric specific populations, several studies have demonstrated that girls tend to have better outcomes after TBI, even after controlling for injury severity. Several studies have demonstrated that girls have better outcomes in relation to learning and memory (Donders & Hoffman, 2002; Donders & Woodward, 2003). Other studies have demonstrated that girls specifically have better outcomes in psychosocial functioning and friendship quality (Anderson et al., 2013; Bohnert, Parker, & Warschausky, 1997; Schwartz et al., 2003).

One possible explanation for gender differences in broad psychosocial functioning after pediatric TBI is the differences in externalizing behavior problems. Schwartz et al. (2003) discovered significant gender differences in externalizing behaviors following pediatric TBI with females having fewer behavior problems. Children with externalizing behavior problems are often noticed and receive attention. However, children without behavior problems, but with genuine impairment often go unnoticed (Stormont, Herman, Reinke, King, & Owens, 2015). Externalizing behaviors have also been associated with subsequent peer rejection (Ettekal & Ladd, 2015; Evans, Fite, Hendrickson, Rubens, & Mages, 2015) Given these associations, it is possible that gender differences in outcome following TBI may be due to gender differences in externalizing behaviors, and “invisible” impairments going unnoticed. Females with autism spectrum disorder, a disorder that is characterized by poor social competence, are also better accepted by their peers when compared to their male counterparts. Several studies have

demonstrated that females are better able to “camouflage” their social deficits by using more gestures, staying in near proximity with their peers, and weaving in and out of activities. It is thought that these differences mask their social deficits (Dean, Harwood, & Kasari, 2017; Rynkiewicz et al., 2016).

Control Group Effects

Research examining the differences between orthopedic injured individuals and typically developing individuals has consistently found that no statistical differences occur. This has been true in both adult samples and pediatric samples (Beauchamp, Landry-Roy, Gravel, Beaudoin, & Bernier, 2017; Mathias, Dennington, Bowden, & Bigler, 2013; Snow, Douglas, & Ponsford, 1997). Our findings related to broad psychosocial outcome is consistent with previous findings, as we found that control group (orthopedic injury vs typically developing) did not moderate the differences in effect sizes between studies. However, on measures of social competence following pediatric TBI, our results suggest that the control group used moderated the differences in effect sizes between studies. Specifically, we found that studies using an orthopedic injury group had smaller effect sizes when compared to studies that used typically developing controls. Although the effects for the orthopedic injury group were smaller, the effects were in the same direction as that of the typically developing controls. One possible reason for this discrepancy may relate to the methods used to analyze this data. Previous studies have examined differences between these two control groups using mean-based analyses (*t*-tests, ANOVA), and they directly compare the two groups with each other and often do not include the TBI groups in the analysis. Our method of analysis was regression-based, and we sought to determine whether or not the control group used could *moderate* effect sizes. We were unable to examine the data using a mean-based approach. Consequently, we could not state whether there

was a statistical difference between orthopedic injury controls and typically developing controls in the studies used in this meta-analysis. However, we found that the type of control group used is a significant moderator and that it adequately predicts effect sizes across studies. These analyses allowed us to examine the effect that control group has in relation to the TBI group. Another possible reason that effect sizes may be smaller in studies that used an orthopedic injury control group may be that orthopedically injured children are more similar to children with TBI pre-injury/baseline. It is possible that both groups are different than typically developing controls at baseline functioning. This line of reasoning is one reason why orthopedic injury control groups were used in the first place: to control for baseline factors (Babikian, McArthur, & Asarnow, 2013; Carroll et al., 2004).

Strengths and Limitations

This meta-analysis had several strengths as well as several limitations. This meta-analysis was the first of its kind to examine parent reported measures of social competence and broad psychosocial functioning following pediatric TBI. It provided a brief, quantitative summary of the effects that TBI has on a child's psychosocial function and social competence. One relative strength was the relatively stringent inclusion and exclusion criteria that was established *a priori*. Only studies using an active control group were included, and each study had to utilize well-accepted and standardized questionnaires of psychosocial functioning and social competence. Our QUADAS-2 ratings also revealed that the studies included were well designed studies and, for the most part, had low risk of bias (with the exception of the index test, which is unavoidable given this population and the necessity for case-control design). After examining the measures used, not only were they well-accepted and standardized measures, but there was some degree of

homogeneity between measures, allowing for combination of these measures with some degree of confidence. The ABAS, VABS, and CBCL were, by far, the most common measures used.

This meta-analysis also had several limitations. First, due to the relatively stringent inclusion and exclusion criteria, a relatively small number of studies actually met criteria and were included in the meta-analysis. Only 16 studies met inclusion criteria and consisted of 849 children with a history of TBI. The moderate TBI group also only had four studies in its analysis, leaving it susceptible to low statistical power. Meta-analyses with a relatively small number of studies are naturally susceptible to the influence of publication bias, and our study is no different. However, this issue was addressed by calculating and reporting fail-safe N test results. Finally, our analysis only included parent report measures of psychosocial functioning and social competence. This was largely due to the heterogeneity in objective neuropsychological measures of social functioning. These measures could not adequately be combined into homogenous effect sizes. Although we were unable to calculate effect sizes for objective neuropsychological data relating to social competence, parent-report is a crucial element to neuropsychological assessment and often represent ecologically valid data (Owens et al., 2015)

Future Directions

After a thorough review of the literature, several gaps were observed in the current literature that require further examination. The first was the need for research related to pediatric TBI to adopt a Research Domain Criteria (RDoC) framework (Cuthbert, 2014). Most of the research related to social competence and psychosocial functioning after pediatric TBI used a diagnosis perspective rather than a symptom perspective. For the specific sample examined in this meta-analysis, it would require researchers to identify children who experience impaired

social competence following TBI rather than looking at social functioning among all children with TBI.

Another essential element that is required in future research of social outcome following pediatric TBI is a standardized and agreed upon assessment battery. Although most of the parent questionnaire data that was used in the current meta-analysis were similar, this was not true of objective neuropsychological measures of social cognition. Bland et al. (2016) have proposed such a battery that has been validated in an adult sample, and it includes measures that are used to assess emotion, motivation, impulsivity and social cognition. Using a battery similar to that proposed by Bland et al. (2016) in a pediatric population would allow for homogeneity of objective neuropsychological data between studies. Subsequently, this would allow for future meta-analyses and systematic reviews to adequately and quantitatively analyze this data in a meaningful way.

Finally, examining ecologically valid outcomes in conjunction with parent questionnaire or lab based tests would allow for a greater understanding of the impact that poor social competence has on day to day functioning following TBI. The Social Outcomes of Brain Injury in Kids (SOBIK) study has utilized unique and ecologically valid measures of a child's social competence. It utilized measures of a child's peer acceptance and peer rejection (as rated by classroom peers), and live observation of peer interaction, as well as questionnaire and neuropsychological data. Using these ecologically valid outcomes would likely improve our understanding of the effect that pediatric TBI has on developing social competence in children and adolescents.

Conclusion

Children with a history of TBI display poorer psychosocial functioning and social competence when compared to their peers. Outcome is also strongly dependent on injury severity, with more severe injuries leading to poorer outcomes. Understanding social outcomes following pediatric TBI has become increasingly important, and greater attention has been paid to these outcomes in recent years. This current meta-analysis provided a quantitative summary of the effect of TBI on social development and social cognition, and meta analytic methods had not been applied to this specific outcome and population prior to this study. Understanding the effects that TBI has on social competence has strong implications for neuropsychological assessment following pediatric TBI, the recommendations that follow these assessments, and current treatment options for these children. As a result, it is likely beneficial to include measures of social function in our neuropsychological assessments, and regularly include early treatment recommendations to address any social impairments that may follow pediatric TBI.

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