Mental health after paediatric concussion: a systematic review and meta-analysis

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ABSTRACT

Objective This systematic review and meta-analysis sought to rigorously examine mental health outcomes following paediatric concussion. To date, heterogeneous findings and methodologies have limited clinicians' and researchers' ability to meaningfully synthesise existing literature. In this context, there is a need to clarify mental health outcomes in a homogeneous sample, controlling for key methodological differences and applying a consistent definition of concussion across studies.

Design Systematic review and meta-analysis.

Data sources We searched Medline, Embase, PsycINFO, CINAHL, SportDiscus, Scopus and PubMed.

Eligibility Peer-reviewed studies published between 1980 and June 2020 that prospectively examined mental health outcomes after paediatric concussion, defined as per the Berlin Consensus Statement on Concussion in Sport.

Results Sixty-nine articles characterising 60 unique samples met inclusion criteria, representing 89 114 children with concussion. Forty articles (33 studies) contributed to a random effects meta-analysis of internalising (withdrawal, anxiety, depression, post-traumatic stress), externalising (conduct problems, aggression, attention, hyperactivity) and total mental health difficulties across three time points post-injury (acute, persisting and chronic). Overall, children with concussion (n=6819) experienced significantly higher levels of internalising (g=0.41–0.46), externalising (g=0.25–0.46) and overall mental health difficulties compared with controls (g=0.18–0.49; n=56 271), with effects decreasing over time.

Summary/conclusions Our review highlights that mental health is central to concussion recovery. Assessment, prevention and intervention of mental health status should be integrated into standard follow-up procedures. Further research is needed to clarify the mechanisms underlying observed relationships between mental health, post-concussion symptoms and other psychosocial factors. Results suggest that concussion may both precipitate and exacerbate mental health difficulties, thus impacting delayed recovery and psychosocial outcomes.

INTRODUCTION

Concussion is a growing public health concern with one-third of children experiencing a head injury before age 13 years.[1] Despite the incidence of concussion among children and adolescents, identifying young people at risk of ongoing difficulties after concussion remains a prominent challenge in the field.[2] Further, evidence shows that children take twice as long to recover from concussion than adults, with one in four children experiencing symptoms beyond 1 month post-injury, defined here as delayed recovery.[3–5] Important differences in the mechanism and context blur the differentiation of sports and non-sports concussion in children and limit the translation of adult findings to paediatric concussion.[6] For example, paediatric concussions are less likely to be sports related and more likely to be due to falls sustained in play or leisure, and more likely to occur in the home or in non-competitive activities.[7] Child and adolescent athletes are also distinguished from older athletes along several dimensions, including biomechanical and pathophysiological responses, and contextual demands (eg, learning vs work).[8]

After concussion, due to either sport or non-sport injuries, children and adolescents are susceptible to a broad range of physical, behavioural, emotional, cognitive, somatic and sleep-related symptoms,[9] many of which overlap with common mental health symptoms. Indeed, evidence suggests that post-concussive symptoms (PCS) correlate highly with internalising symptoms such as anxiety[10] and depression,[11 12] with premorbid mental illness identified as a key risk factor for delayed recovery.[13] Mental health screening may provide an avenue for early detection and targeted interventions for children at risk of delayed recovery due to mental health symptoms. Despite the potential role that these behavioural and emotional disturbances may play in delayed recovery, few studies have rigorously examined this relationship.[14]

Research designs employed in studies investigating mental health outcomes after paediatric concussion have, to date, been heterogeneous, limiting opportunities for qualitative and quantitative synthesis.[14] Variable definitions of concussion adopted across studies are a key contributing factor to this heterogeneity. Further, combining traumatic brain injury (TBI) severity groups for analysis, unclear eligibility criteria (eg, pre-injury mental health status), differences in recruitment methods (eg, inpatient, outpatient, community), nature of comparison groups and timing of outcome measurement all contribute to variability. Not surprisingly, results are also inconsistent with some studies reporting persistent mental health symptoms,[15–18] while others report no such findings.[19 20]

Despite methodological challenges, several robust findings are reported in the literature. Female adolescents are particularly vulnerable to internalising difficulties such as depression, anxiety and withdrawal after concussion.[21] Meanwhile, externalising behaviours, such as conduct problems, attention difficulties, hyperactivity and temper problems are more common among younger children.[22] Whether these findings reflect risk factors associated with participant factors, such as age and sex, versus design characteristics require further exploration.

Two previous reviews have examined psychiatric outcomes from paediatric mild TBI (mTBI), however, both merged concussion, mTBI and complicated mTBI

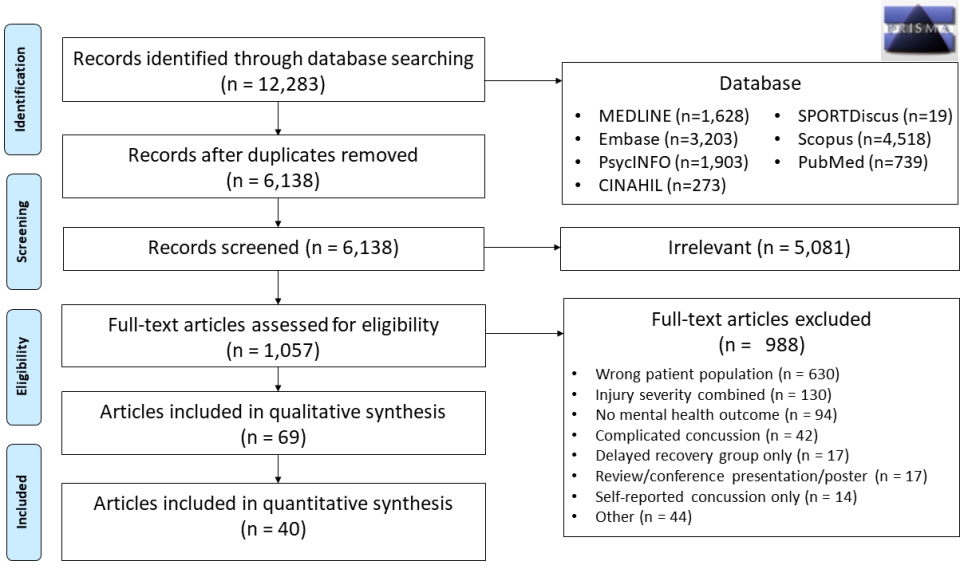

Figure 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow chart.

in their syntheses.[14 23] These reviews emphasise high levels of variability in study findings, concluding that evidence for mental health difficulties following paediatric mTBI is inconclusive. Nonetheless, several important distinctions between these diagnoses should be acknowledged. In mTBI, recovery profiles for injuries with and without structural brain abnormalities display distinct characteristics, with structural injuries associated with slower recovery and poorer functional outcomes across cognitive, academic and social domains than when no structural injury is detected.[24–31] In the present study, we have applied the definition of concussion from the Berlin Consensus Statement of Concussion in Sport (CISG), specifically 'an acute functional disturbance coupled with post-concussion symptoms, but without evidence of structural brain injury and generally associated with the expectation of better recovery than mTBI'.[9] While this definition was derived with a focus on sports concussion, it refers to injury consequences and is equally applicable to concussions sustained outside organised sport.

The objective of this review was to systematically examine prospective mental health outcomes following paediatric concussion, applying a consistent definition of concussion across studies. Specifically, we sought to address the following research questions: (1) How common are mental health difficulties after paediatric concussion? (2) What factors predict mental health following paediatric concussion? (3) How do mental health problems interact with recovery from concussion? and (4) How does mental health status change with time post-injury? We conducted a meta-analysis to determine if children experienced elevated mental health difficulties after concussion compared with controls.

MATERIALS AND METHODS

Protocol registration

The review protocol was registered with the International Prospective Register of Systematic Reviews (#147741).

Methods

This systematic review was conducted according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines and identified articles published from 1980 to June 2020 using the search strategy shown in online supplemental table 1. This time frame was selected due to the considerable changes in the understanding of concussion over the past 40 years and the large number of articles identified in preliminary searches. The final search was conducted in June 2020. Studies identified through systematic searches of Medline, Embase, PsycINFO, CINAHL and SportDiscus. Keyword only searches were conducted through Scopus and PubMed to identify articles not captured via the above sources. Two postgraduate authors (AG, TM) independently screened titles and abstracts using Covidence Systematic Review Software.[32] Articles identified as relevant in this phase were reviewed in full text (AG, XL), according to the eligibility criteria outlined below. Reviewers were blind to one another's decision at the time of voting. Any discrepancies highlighted by the software were resolved by consensus, and a third senior clinical researcher (MT) was consulted if additional expertise was required.

Eligibility criteria

This review included peer-reviewed articles reporting prospective mental health outcomes following concussion in paediatric populations (age 0–18 years at time of injury). To increase the application of present findings to inform policy and practice, this review considered quantitative, qualitative and mixed-methods studies. Quantitative studies included observational designs, prospective and retrospective cohort studies, case–control studies and analytical cross-sectional studies. Qualitative studies included, but were not limited to, phenomenology, grounded theory, ethnography and action research. Mixed-method studies were considered if data from the quantitative or qualitative components could be extracted.

Concussion was defined according to the Berlin CISG Criteria and required diagnosis by a health professional or administration of a clinically validated measure.[9] The Berlin CISG Criteria were developed using rigorous methodology, including systematic review of the literature and expert panel consensus. Studies were eligible for inclusion if the concussion definition was consistent with the Berlin CISG Criteria, regardless of whether or not these criteria were explicitly cited.

Seventeen authors were contacted to clarify whether participants satisfied present criteria for concussion. Intervention studies that did not report prospective mental health outcomes for a non-intervention concussion group, studies that combined injury severities (eg, did not differentiate between concussion

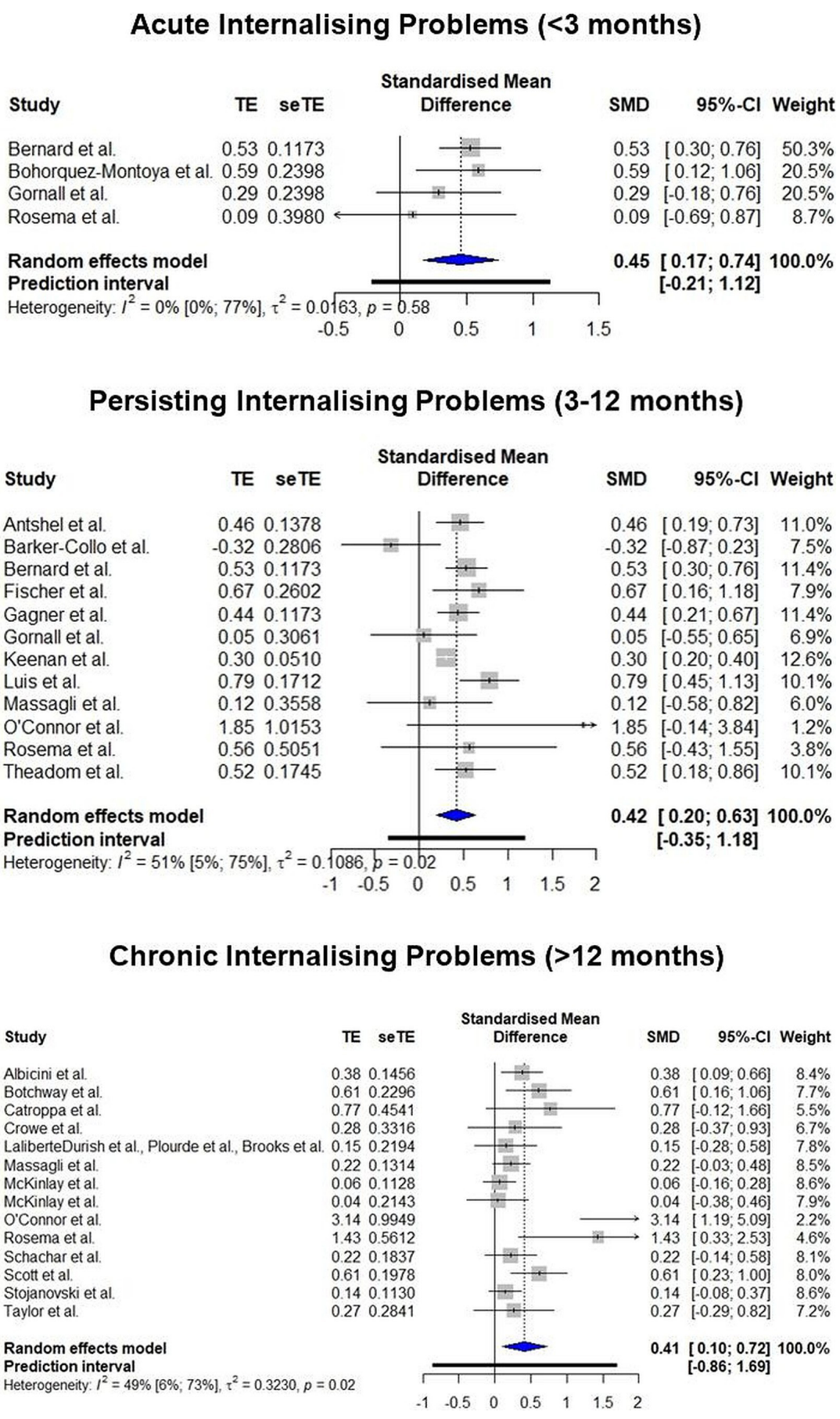

Figure 2 Standard mean difference (SMD), treatment effect (TE) and standard error (seTE) of acute, persisting and chronic internalising problems after paediatric concussion.

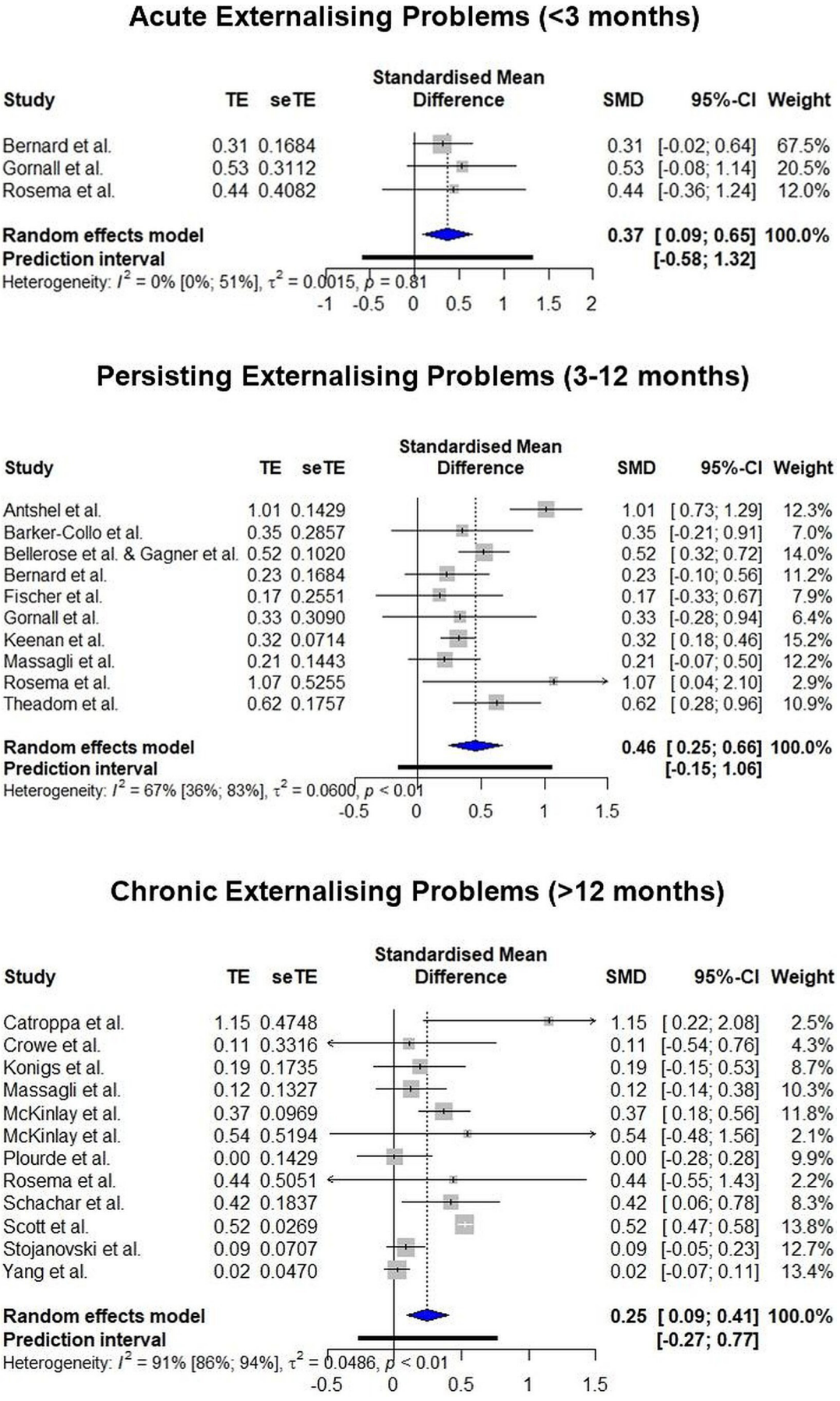

Figure 3 Standard mean difference (SMD), treatment effect (TE) and standard error (seTE) of acute, persisting and chronic externalising problems after paediatric concussion.

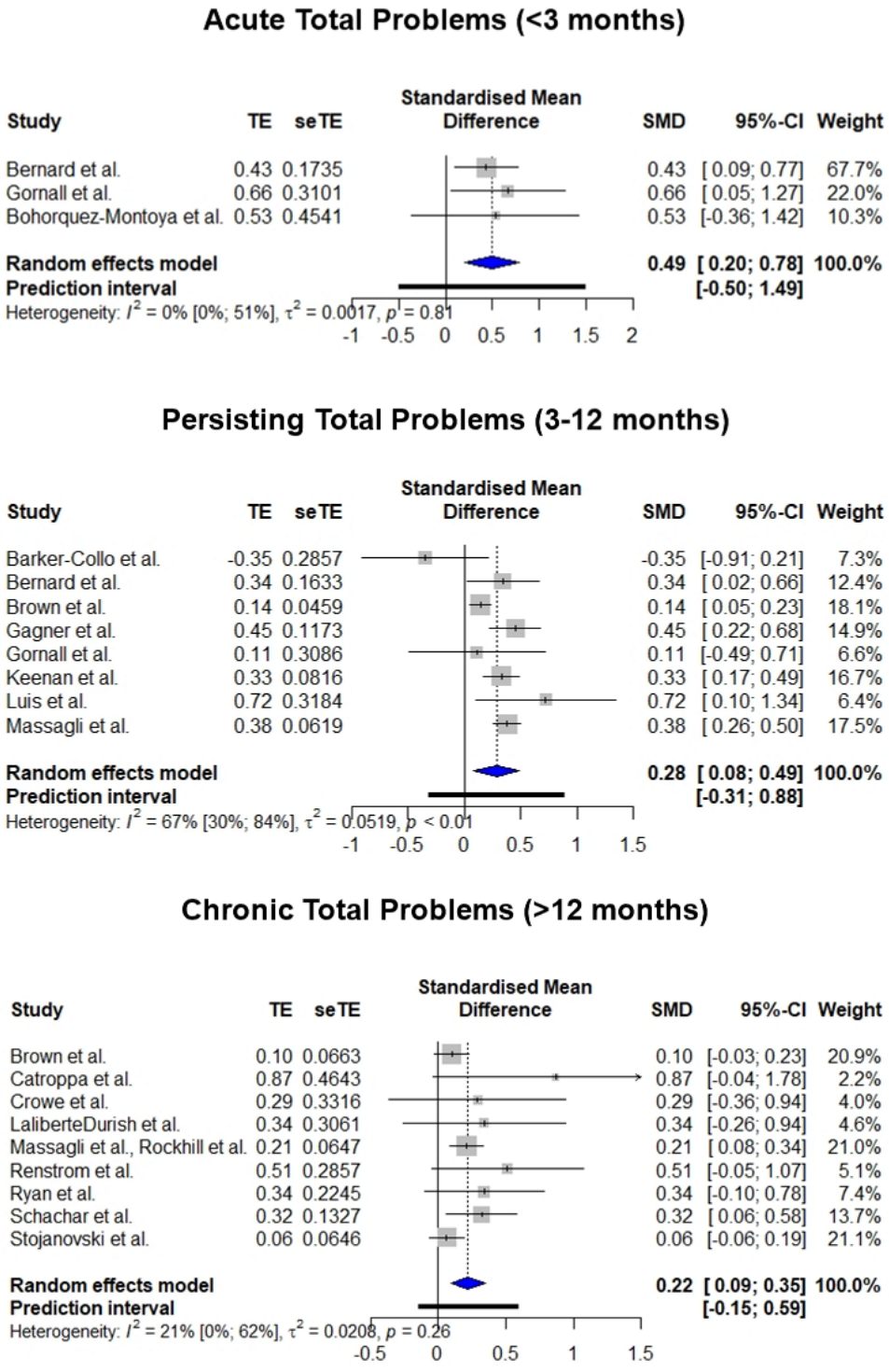

Figure 4 Standard mean difference (SMD), treatment effect (TE) and standard error (seTE) of acute, persisting and chronic total mental health problems after paediatric concussion.

and mTBI/complicated mTBI) and studies that only reported mental health outcomes for children with delayed recovery were excluded. Reviews, meta-analyses, case studies, conference abstracts, book chapters, commentaries, dissertations, case reports and non-English articles were also excluded.

Eligible studies that included an orthopaedic injury or typically developing control group were included in meta-analyses, while studies that did not include a control group were included in the systematic review only (n=36).

Data classification

Mental health outcomes were restricted to the broad categories of internalising, externalising and total mental health difficulties, due to the few studies reporting findings at a disorder-specific level. The American Psychological Association endorses the utility of the internalising/externalising framework in research and clinical contexts in their introduction to the Diagnostic and Statistical Manual of Mental Disorders-fifth edition (p.13):

> …clustering of disorders according to what has been termed internalizing and externalizing factors represents an empirically supported framework. Within both the internalizing group (representing disorders with prominent anxiety, depressive, and somatic symptoms) and the externalizing group (representing disorders with prominent impulsive, disruptive conduct, and substance use symptoms), the sharing of genetic and environmental risk factors, as shown by twin studies, likely explains much of the systematic comorbidities seen in both clinical and community samples.[33]

In keeping with the internalising/externalising framework, anxiety, depression, post-traumatic stress and withdrawal were indexed under internalising problems while aggression, conduct problems, attention problems, risk-taking and hyperactivity were classified as externalising problems.[33–36] Overall mental health was measured by novel psychiatric diagnoses post-injury as well as total problem subscales of validated behavioural and emotional inventories. Pooled effect sizes were calculated for studies reporting results from multiple informants (eg, parent and child self-report) and for different outcomes underlying the same construct.

Evidence suggests that mental health changes with time post-concussion.[21] However, it is unclear how internalising and externalising difficulties may evolve from very acute stages to longer term impact. We therefore included a wider range of time since injury, to capture and comment on time in the context of recovery. Existing published concussion guidelines and recovery trajectories were used to define time since injury categories. Insufficient data (n=1) were available to analyse outcomes ≤1 month post-injury. Therefore, time points were defined as follows: (1) acute: injury to <3 months post-injury, the time frame when most young people recover from concussion[8 9]; (2) persisting: 3–12 months post-injury, the time frame when a minority of children experience ongoing symptoms[8 37]; and (3) chronic: >12 months post-injury, the time frame when most novel mental health difficulties have emerged,[17] reflecting the longer term impact on mental health.[5] Studies were assigned to these categories using the mean time since injury at each assessed time point. Where multiple data points were measured within the same time category, results were pooled into a single effect size.

Quality assessment

The quality of eligible studies was assessed using the Downs and Black Quality Appraisal Criteria (DBC) which assigns non-intervention studies a maximum of 20 points for the highest quality across five main criteria: (a) external validity, (b) reporting, (c) bias, (d) confounding and (e) power.[38] The Oxford Centre for Evidence-Based Medicine (OCEBM) 2011 Levels of Evidence were also employed as a measure of evidence strength informed by research design.[39]

Meta-analyses

Random effects meta-analyses were conducted using *meta*,[40] *metafor*[41] and *dmetar* packages in R V.4.0.2.[42 43] Means and SDs were used to calculate effect sizes for continuous mental health outcomes, while frequencies of events in cases and controls were used to calculate effect sizes for categorical variables. Where studies did not report adequate data to calculate effect size, the corresponding author was contacted (n=7). Studies that could not be included in the meta-analysis because appropriate data were not provided were included in the systematic review only (n=2).

Effect size was measured using Hedges' g as it adjusts for sample size, thus providing an unbiased estimate of the standardised mean difference.[44] Consistent with established recommendations for meta-analysis, effect sizes were interpreted as small (0.32), moderate (0.33–0.55) or large (>0.59).[45] Heterogeneity was quantified using the I^2 statistic which describes the percentage of variability in effect sizes due to heterogeneity rather than chance alone.[46] Heterogeneity was interpreted as low, or unimportant (0%–30%), moderate (30%–50%), substantial (50%–80%) and considerable (80%–100%).[47] Graphic Display of Heterogeneity (GOSH) plots were generated to explore patterns of heterogeneity, followed by sensitivity analyses.[48] Heterogeneity was further explored through subgroup analyses and meta-regression where sufficient data were available (n≥10).[49] Some prespecified analyses were unable to be conducted due to missing data (eg, premorbid mental health status) and were substituted for available alternatives (eg, exclusion of patients with psychiatric history). Influence analyses (eg, 'leave-one-out' approaches) were conducted to ensure that the overall estimate of the meta-analysis was not distorted by outliers or studies exerting high influence on the model.[50]

RESULTS

Study selection

The study selection process is illustrated in figure 1. Sixty-nine articles representing 60 unique samples satisfied eligibility criteria and were included in the systematic review. Of these, 29 were excluded from the meta-analysis due to the absence of a control group, or because controls did not complete mental health measures, resulting in 40 articles characterising 33 unique studies included in the meta-analytical review. Characteristics and main findings of included studies are displayed in online supplemental table 2.

Study characteristics

In total, 89 114 children with concussion (60.9% males) were represented in this meta-analysis. Age at injury ranged from 0 to 18 years, with a weighted grand mean of 11.69 years. Falls (42.3%) and sporting injuries (29.5%) were the most common injury mechanisms reported, followed by motor vehicle accidents (15.5%).

One-third of included studies used a prospective longitudinal design (n=20). The remaining studies used prospective cohort (n=11), cross-sectional (n=9), retrospective cohort (n=9), case–controlled (n=5), inception cohort (n=3), qualitative (n=2), retrospective chart review (n=1) and repeated measures (n=1) designs.

Assessed time points ranged from admission to 20 years post-injury. All studies used age-appropriate, validated measures of mental health (n=60), comprehensive interviews (n=2), formal psychiatric diagnoses (n=3) or engagement with mental health services (n=3) to detect mental health outcomes. The Child Behavior Checklist (n=19, 27.5%), Behavior Assessment System for Children (n=7, 10.1%) and Personality Inventory for Children (n=7, 10.1%) were the most commonly used measures. Other instruments used are listed in online supplemental table 2. Internalising problems were the most frequently assessed mental health outcomes (n=43), followed by overall mental health (n=32) and externalising problems (n=29). Parents were the most frequent respondents (n=43), followed by children (n=28) and teachers (n=7). Fifteen studies included multiple informants (parent and child, n=8; parent and teacher, n=6; parent, child and teacher n=1).

Premorbid mental health status was assessed in 28 studies (40.6%), as documented by retrospective ratings of pre-injury behaviour (n=19) or psychiatric diagnoses (n=9). Two studies employed International Classification of Disease Criteria-10, while seven studies did not specify the criteria for pre-injury mental health diagnoses. Thirty-two studies (46.3%) excluded children either with a history of mental health difficulties or hospitalisation for psychiatric illness. Twenty-one (30.4%) of the included studies did not account for pre-injury mental health status, nor exclude children with pre-injury mental health diagnoses, while 12 (17.4%) excluded pre-injury mental health diagnoses and included measures of premorbid mental health. Additional study characteristics have been outlined in online supplemental material.

Quality assessment

All included studies were rated as excellent (n=41, 61.2%) or good (n=26, 38.8%) quality on the DBC. Most included studies represented level 3 evidence according to the OCEBM Levels of Evidence (n=58, 82.9%), with seven inception cohort studies meeting criteria for level 2 (10.0%) and three studies at level 4 (4.3%). Forty-three studies (61.4%) recruited participants via consecutive admissions or inception cohort design, suggesting low risk of selection bias among most included studies. Twenty-two studies (55.0%) in the meta-analysis recruited controls from the same setting as concussion sample, suggesting risk of selection bias.

Reporting of attrition rates was fair, with 42 studies (60.9%) describing both proportion and characteristics of participants lost to follow-up. Forty-four studies reported low attrition rates (<20%) or adjusted analyses based on confounds related to patients lost to follow-up (63.8%). Fifty studies (72.5%) had clear aims and hypotheses. Five (7.2%) included power calculations. All reported key participant characteristics of patients, and the majority (n=64, 92.8%) detailed the distribution of key confounders. Of studies included in the meta-analysis, comparability between cases and controls was acceptable, with 34 (85.0%) documenting principal confounds and all studies either demonstrating no significant group differences or making adequate adjustments for confounds.

Systematic review

The results of included studies are qualitatively synthesised below, corresponding to study research questions.

How common are mental health problems after paediatric concussion?

Twenty-nine articles addressed this question. Studies consistently reported that a minority of children experienced clinically significant levels of internalising, externalising and total mental health problems after concussion[16–18 28 51–59]: 19.3%–40.0% of whom reported no pre-injury mental health symptoms and 50.0%–60.0% reported a history of elevated pre-injury mental health symptoms[56–58] or diagnoses.[17 18] Twenty-nine per cent of children with pre-injury mental health diagnoses received a novel mental health diagnosis post-concussion.[17] Internalising, externalising and total mental health problems were reported within the normal range in most studies.[21 60–64] One study reported mean behaviour problems in the clinical range 3 months post-injury with resolution by 6 months.[61]

The prevalence of clinically significant internalising problems ranged from 3.0% to 36.7%,[54 65–68] with one study reporting 40% of children demonstrated subclinical anxiety following concussion.[69] Although parents reported their child's inability to control anger among the most distressing symptoms,[70] just one study reported the proportion of clinical externalising problems following concussion, at 20.0% 16 years post-injury.[71] Results from a population-based study by McKinlay *et al* found that preschool children who attended hospital for concussion were three to four times more likely to show symptoms of attention-deficit/hyperactivity disorder, conduct disorder, oppositional defiant disorder, substance abuse and mood disorder during early adolescence, compared with typically developing controls and children who presented to outpatient services after concussion.[28 51]

What factors predict mental health following paediatric concussion?

Studies reported several factors influenced mental health after paediatric concussion (n=28). Pre-injury mental health was consistently identified as a strong predictor of post-injury mental health problems.[16 17 57 66 72 73] Five studies systematically examined this relationship with regression analyses and demonstrated that psychiatric history explained between 38.4% and 65.0% of variance in mental health problems post-concussion.[16 17 66 73 74] Age and sex were inconsistent predictors of mental illness. Internalising vulnerabilities were associated with female sex[21 22 52 75–77] and older age at injury.[17 21 60 61 78] Females appeared at greater risk of developing novel mental health difficulties after concussion,[21 52 75 76] but this finding was not universal.[17 55] Males with a psychiatric history were at increased risk of developing further psychiatric illness after concussion.[17] Younger age at injury was associated with more externalising problems[17 22] and post-traumatic stress symptoms,[76] however some studies found no association between age and mental health or psychosocial functioning.[65 69] While several studies indicated a role for family factors,[17 18 52 57 68 79 80] only five studies explored family characteristics post-concussion.[16 22 72 80 81] Results showed that family functioning, parent mental health, parent distress and family characteristics (eg, family living arrangement, parent education) were associated with externalising problems 6 months after concussion.[16 22 72 80 81] In contrast, family characteristics did not predict internalising problems above and beyond participant characteristics.[16]

Two studies explored protective factors associated with better mental health outcomes, identifying positive family environment, cultural and psychological resilience as associated with better quality of life and lower levels of depression, anxiety, adjustment and attention-deficit/hyperactivity symptoms.[22 75]

How does mental health interact with recovery from concussion?

Few studies directly examined the interaction between mental health and PCS (n=11). Internalising symptoms significantly predicted acute and post-acute PCS.[5 75 82] Higher premorbid PCS predicted increased psychological difficulties over time.[52 73] Nonetheless, even when taking pre-injury data into account, considerable variation in recovery trajectories exists.[56]

How does mental health change with time post-injury?

In the nine studies addressing this issue, mental health symptom profile tended to remain stable over time,[69] with most novel psychiatric diagnoses developing in the first-year post-concussion.[17] Significant improvements in mental health emerged between 3 and 6 months post-injury.[21 72 83] Among infants and toddlers, social and emotional behaviour worsened over time,[84] with significantly higher rates of conduct, oppositional defiant,

attention-deficit/hyperactivity, substance use and mood disorder symptoms evident several years post-concussion.[28]

Meta-analyses

We then conducted meta-analyses to determine if children experienced elevated mental health difficulties after concussion compared with controls.

Internalising problems

Significant, moderate effects were observed in the concussion group compared with controls across acute (t=5.12, g=0.45, 95% CI (0.17 to 0.74), p=0.01) persisting (t=4.26, g=0.42, 95% CI (0.20 to 0.63), p=0.001) and chronic (t=2.88, g=0.41, 95% CI (0.10 to 0.72), p=0.01) outcomes (see figure 2). At each time point, there was a large prediction interval and low to considerable heterogeneity (acute: I^2=0.0%, 95% CI (0.0% to 76.8%), Q(3)=1.98, p=0.58; persisting: I^2=51.0%, 95% CI (5.3% to 74.7%), Q(11)=22.46, p=0.02; chronic: I^2=49.3%, 95% CI (6.2% to 72.6%), Q(13)=25.67, p=0.02). GOSH diagnostics identified outliers contributing to cluster imbalance in both persisting (n=2) and chronic models (n=4). Pooled estimates remained significant omitting these outliers and heterogeneity was low to moderate (persisting: g=0.46, 95% CI (0.32 to 0.59), p<0.0001, I^2=36.1%; chronic: g=0.27, 95% CI (0.11 to 0.42), p=0.003, I^2=28.9%; online supplemental figure 1). Leave-one-out analyses revealed that all pooled estimates after excluding one study at a time fell within the 95% CI of the overall estimate. Funnel plots and Egger's test showed evidence of publication bias in chronic internalising outcomes (p=0.003). Nonetheless, p-curve analyses supported evidential value suggesting that a true effect size underlies presented findings and that results are not the product of publication bias and p-hacking alone.

Externalising problems

Significant, moderate effect sizes were observed across acute (t=5.77, p=0.03, g=0.37, 95% CI (0.09 to 0.65)) and persisting (t=4.94, p<0.001, g=0.46, 95% CI (0.25 to 0.66)) time points, decreasing to a small effect in the chronic model (t=3.46, p=0.005, g=0.25, 95% CI (0.09 to 0.41); see figure 3). Heterogeneity was low to moderate and non-significant for acute externalising problems (I^2=0.00%, 95% CI (0.00% to 50.5%), Q(2)=0.42, p=0.81) but substantial and significant among studies investigating persisting (I^2=66.9%, 95% CI (35.5% to 83.0%), Q(9)=27.18, p=0.001) and chronic effects (I^2=90.7%, 95% CI (85.7% to 94.0%), Q(11)=118.32, p<0.0001). GOSH diagnostics identified outliers contributing to cluster imbalance in both persisting (n=3) and chronic models (n=3). We reperformed the meta-analyses omitting outliers and the pooled estimates remained significant with low heterogeneity (g=0.38, 95% CI (0.21 to 0.54), p=0.001, I^2=8.4%; g=0.19, 95% CI (0.07 to 0.32), p=0.007, I^2=18.8%; online supplemental figure 2). Leave-one-out analyses revealed that all pooled estimates after excluding one study at a time fell within the 95% CI of the overall estimate. No evidence of publication bias was identified on funnel plots or Egger's test. Evidential values supported a true effect size underlying present results.

Total problems

Significant, small to moderate effects were observed across acute (t=7.34, p=0.02, g=0.49, 95% CI (0.20 to 0.78)), persisting (t=3.24, p=0.01, g=0.28, 95% CI (0.08 to 0.49)) and chronic total mental health problems (t=3.91, p=0.005, g=0.22, 95% CI (0.09 to 0.35)), with effect size decreasing over time (see figure 4). Heterogeneity was low to moderate and non-significant across the acute (I^2=0.00%, 95% CI (0.00% to 51.4%), Q(2)=0.43, p=0.81) and chronic time points (I^2=20.7%, 95% CI (0.00% to 62.0%), Q(8)=10.09, p=0.26), but moderate to high in the persisting model (I^2=66.7%, 95% CI (29.6% to 84.3%), Q(7)=21.03, p=0.004). GOSH diagnostics identified outliers contributing to cluster imbalance in both persisting (n=2) and chronic models (n=1). We reperformed meta-analyses omitting outliers, and pooled estimates remained significant with low heterogeneity (g=0.38, 95% CI (0.26 to 0.49), p=0.0004, I^2=0.0%; g=0.18, 95% CI (0.08 to 0.29), p=0.004, I^2=9.4%; online supplemental figure 3). Leave-one-out analyses revealed that all pooled estimates after excluding one study at a time fell within the 95% CI of the overall estimate. Chronic, but not persisting, outcomes showed evidence of publication bias on funnel plot and Egger's test (p=0.02); however, evidential values supported a true underlying effect.

Additional analyses

Meta-analyses stratified by age and sex were not possible due to the lack of age-specific and sex-specific data reported in the included studies. Meta-regressions evaluating the impact of sex (% males) and age (mean age) on mental health were, therefore, conducted. Variability in persisting internalising and externalising outcomes was not explained by any of the demographic or methodological factors examined (see online supplemental tables 2 and 3). Chronic internalising problems significantly differed by OCEBM Level of Evidence, with level 3 studies showing the greatest effect size (g=0.51), followed by levels 4 (g=0.38) and 2 (g=0.10). Sex and DBC quality rating accounted for 7.78% and 5.63% of variance, respectively, but were non-significant predictors overall. In the chronic externalising model, mean age accounted for 5.00% of variance, but was a non-significant predictor overall. As with persisting outcomes, no other factors significantly accounted for heterogeneity at the chronic time point. Insufficient studies were available to conduct subgroup analyses or meta-regressions on total behaviour problems. Online supplemental figures 4–7 present forest plots by design and respondent.

DISCUSSION

The aim of our paper was to systematically investigate mental health outcomes following paediatric concussion while controlling for key methodological differences that have limited synthesis of paediatric concussion research. Our results revealed that mental health is highly relevant to concussion recovery. Both the qualitative synthesis and meta-analysis demonstrated that, even among studies with homogeneous designs, samples and concussion definitions, mental health outcomes can vary widely. This indicates that children respond to concussion in diverse ways. While mental health generally improves with time post-injury, a minority of children experience clinically significant and persisting mental health symptoms that warrant clinical attention. Post-traumatic stress and depressive symptoms in particular have been associated with increased risk for adverse outcomes after concussion.[54 85] Evidence suggests that pre-existing mental health symptoms, family anxiety, the psychosocial impact of post-concussion symptoms and reduced activity may contribute to ongoing mental health symptoms in this group.[16 17 57 66 72 73 86–88] Despite this chronic vulnerability, only a small proportion of children

access mental healthcare after concussion,[52 59] highlighting this as a missed opportunity for early intervention.

In contrast to recovery from PCS more generally,[8] few studies reported significant improvements in mental health symptoms by 1 month post-injury,[83] suggesting that mental health symptoms may take longer to resolve than other post-concussion symptoms. This suggests that concussion is an important factor precipitating subsequent mental health symptoms, which may be maintained by biopsychosocial factors related to concussion (eg, fatigue) and context (eg, worry about repeat injury). Of note, the most commonly employed measures of PCS include symptoms that overlap considerably with mental health (eg, emotional lability, irritability, nervousness, sadness), leading to difficulties differentiating PCS and mental health symptoms.[89] Despite this confound, few studies commented on the potential overlap in measurement of these two dimensions. This relationship may be driven by a high level of symptom overlap between PCS and mental health difficulties, or by a feedback loop where persisting PCS precipitate acute stress which then exacerbates mental health symptoms, which further impacts PCS.

The less competitive nature of sport among younger children contributes difficulties differentiating sport from non-sport concussion in paediatrics. Therefore, little research has been conducted on sport concussion in children under 13 years,[9] despite a significant proportion of paediatric concussions sustained during sport.[90] Sport-concussion research is important given the increased risk of repeated concussions,[9] which has been associated with mental health difficulties and delayed recovery.[4 14] Results from this review highlight that mental health outcomes from sport[53 77 82 91] and non-sport concussion are broadly consistent, despite greater representation of older children and adolescents in sport concussion research. While clinical recommendations for non-sport-related concussions are lacking, these findings highlight that, alongside clinical judgement, sport-related concussion guidelines are likely to be highly relevant to the assessment and management of non-sport concussion.

Current evidence establishes pre-injury mental health difficulties as the strongest and most consistent predictor of post-concussion mental health outcomes; however, novel diagnoses occur in approximately one-third of young people after concussion.[17] Female sex was associated with increased internalising problems after concussion, however, this vulnerability is also evident in the general population and is unlikely to be concussion specific. Age was an inconsistent predictor of mental health outcomes. Interaction effects between age and sex are a potential explanation for this variability with internalising problems increasing with age among females.[21] Given that female sex and older adolescence have also been identified as risk factors for delayed recovery following concussion,[4] present results may reflect vulnerability to adverse outcomes from concussion more broadly, the emergence of mental health difficulties observed among females during adolescence, or an interaction between these factors and their psychosocial context.

Infants and toddlers may also experience social and emotional difficulties that worsen over time,[84] with significantly higher rates of conduct, oppositional defiant, attention-deficit/hyperactivity, substance use and mood disorder symptoms evident several years post-concussion.[28] This finding might be explained by the fact that younger children are less likely to have existing mental health diagnoses, reflect developmentally specific neurobehavioural outcomes, family anxiety, incidental reinforcement of maladaptive coping (eg, reassurance seeking, separation anxiety) or a combination of these factors. Further research is needed to explore the relationship between concussion, mental health and child development in greater detail.

Psychological resilience and family characteristics emerged as promising, but largely unexplored, predictors of post-concussion mental health outcomes. Given these domains offer the potential for early intervention, further exploration of these factors may provide opportunities to improve mental health outcomes.

Consistent with reviews of elite collegiate athletes,[92] our results support an association between concussion and acute internalising mental health symptoms. While depressive symptoms in elite collegiate athletes resolve within 1 month post-concussion,[92] our review suggests that both internalising and externalising problems persist longer in children and adolescents. Such long-term mental health problems have also been highlighted in a narrative review of suicidality after concussion and mTBI among children, adults and military personnel, showing a twofold greater risk of suicide compared with peers.[93] Our review extends our understanding of mental health consequences of concussion to children and adolescents, who may be at greatest risk of adverse outcomes.[9]

This systematic review and meta-analysis included studies employing a variety of designs, providing an opportunity to explore the impact of research design on study results. Prospective cohort and longitudinal prospective cohorts generally found larger effects than cross-sectional, case–control, retrospective cohort and inception cohort designs. This may reflect bias in reporting positive results or strengths of prospective cohort designs, including accuracy of data collection regarding exposures, confounders and timing of concussion. Population studies often revealed long-term impacts that were not evident in many retrospective designs.[59 65 94–96] Consistent with population data,[27 28 51 78 97] several prospective longitudinal cohort studies reported increased mental health difficulties several years post-concussion.[15 16 57 62 71 75 98]

Clinical implications

Results from our review highlight the importance of considering mental health as a predisposing, exacerbating and protective factor for concussion recovery. Findings that PCS subtypes are relatively stable over time since injury[17 69] highlight the potential and importance of early intervention. When making recommendations for concussion management, clinicians should consider potential mental health consequences, particularly where premorbid mental health difficulties are present.

Previous management approaches, such as prolonged rest, have been associated with poor mental health and adverse outcomes after concussion.[87 88] Current clinical guidelines for recovery support a systematic and graduated return to exercise, school and sport.[9 99 100] The CISG Berlin Consensus Statement outlines the importance of applying this protocol alongside clinical judgement, on an individual basis.[9] The statement further highlights the utility of structured interventions, such as graded exercise[101] and physiotherapy tailored to individual symptoms.[102 103] Less is known about treatment of mental health symptoms, with initial promise shown with the use of cognitive–behavioural paradigms,[104] either alone or as part of collaborative care models. The trajectories of PCS and mental health symptoms are closely intertwined among children with

delayed recovery,[105] further demonstrating mental health as an important target for intervention.

Since the majority of children and adolescents with clinical mental health difficulties do not access recommended care,[106] incorporating mental health risk into post-injury management represents an avenue to engage young people with mental health services to either prevent unnecessary problems emerging or to treat premorbid issues.

The presence of psychological distress is associated with twice the healthcare costs after paediatric concussion,[107] further highlighting the importance of early intervention. When assessing persisting post-concussion symptoms, clinicians should be cognisant of the potential overlap between PCS and mental health symptoms. As a first step, mental health should be evaluated as part of standard acute concussion assessment and management. This may encourage families to monitor and seek support for emerging or exacerbated emotional and psychological symptoms. Among children with delayed recovery, parent anxiety contributes additional family burden following childhood concussion, indicating a need for management strategies to consider the implications to the entire family.[86]

Anxiety and depression significantly mediated the relationship between resilience and post-concussion symptoms,[108] suggesting that mental health has an important impact on recovery from concussion, even accounting for individual characteristics. While children provided different reasons for their emotional distress (eg, inability to play sport, others' lack of understanding about concussion), they consistently reported frustration, depression, anxiety, irritability and feelings of isolation associated with their injury.[91] Considered together, current evidence supports the use of a biopsychosocial model for understanding the factors contributing to the development and maintenance of mental health difficulties post-concussion on an individual basis.

Strengths and limitations

This systematic review extends past literature by focusing specifically on mental health after concussion in a paediatric population and is among the first to perform a meta-analysis. Major strengths are precise inclusion criteria, thorough search strategy and robust evaluation. Nonetheless, several limitations need to be acknowledged. First, we excluded unpublished and non-English language articles, which may subject findings to publication and language bias. Although risk of publication bias was identified for some comparisons, further analyses supported the presence of a true effect underlying results. This systematic review and meta-analysis included studies employing a variety of designs, assessment tools and respondents. While this can increase heterogeneity, it also provides an important opportunity to comment on the impact of research design on mental health outcomes and focus of past research. To balance these considerations, we restricted inclusion to studies that measured mental health prospectively, regardless of how other unrelated measures were obtained. Considering the relatively small number of studies and the results of subgroup analyses conducted, the impact on the overall conclusions is minimal.

Limitations of the literature

At a study level, only four studies explored mental health outcomes within the first 3 months of concussion. Forty-one studies (59.4%) addressed mental health as the primary

What is already known?

- Concussion is a common injury among children and adolescents.
- While some studies report significant mental health problems after childhood concussion, other studies report no such finding.
- Several post-concussion symptoms overlap with mental health symptoms, however, the relationship between delayed recovery and mental health remains poorly understood.

What are the new findings?

- Mental health is highly relevant to concussion recovery, although the ways children respond to concussion are diverse.
- A minority of children experience clinically significant mental health symptoms that warrant clinical attention, particularly in the presence of post-traumatic stress symptoms and depression.
- Current evidence establishes pre-injury mental health difficulties as the strongest and most consistent predictor of paediatric post-concussion mental health outcomes, however, novel diagnoses occur in approximately one-third of young people after concussion.
- Psychological resilience and family characteristics are promising, but largely unexplored, predictors of post-concussion mental health outcomes.
- In contrast to recovery from post-concussion symptoms more generally, mental health symptoms may take longer than 1 month to resolve.
- Current evidence supports the use of a biopsychosocial model for understanding the factors contributing to the development and maintenance of mental health difficulties post-concussion on an individual basis.

How might it impact on clinical practice in the future?

- Mental health should be evaluated as part of standard paediatric concussion assessment and management in the context of biopsychosocial factors.
- Mental health should be considered a potential predisposing, exacerbating and protective factor for paediatric concussion recovery.
- When making recommendations for concussion management in children, clinicians should consider potential mental health consequences, particularly where premorbid mental health difficulties are present.
- Incorporating mental health risk into post-injury management represents an avenue to engage young people with mental health services to either prevent unnecessary problems emerging or to treat premorbid issues.
- When assessing persisting post-concussive symptoms in children, clinicians should be cognisant of the potential overlap between post-concussive symptoms and mental health symptoms.

outcome. In the remaining studies, mental health was a secondary consideration to cognition (n=11), physiology (n=10), sleep (n=3) or quality of life related (n=4). Only two studies separated mental health data by sex and age group, highlighting significant gaps in past research and limiting the generalisability of acute findings.

Pre-injury mental health was reported in less than half of the included studies. While most of these studies employed a validated measure of pre-injury mental health, few reported the criteria for formal diagnosis. Most studies relied on normed and validated parent or self-report mental health measures. While child respondents generally reported more mental health difficulties than parents and diagnoses reported in medical records, results were broadly consistent across studies. Studies including multiple respondents showed lower variability than single respondents highlighting valuable increase in precision. Finally, although 69 studies were identified as eligible for the systematic review, nearly half of these were excluded from the meta-analysis due to the absence of a control group.

Future directions

Future studies seeking to address design limitations should aim to assess pre-injury mental health, incorporate clinical assessment and include multiple respondents with a robust, clearly defined measure of pre-injury mental health. Reporting age-specific and sex-specific results will clarify the relationship to mental health outcomes highlighted in this review. Methodology would be strengthened by including a control group, reporting power analyses and continuing to minimise bias wherever possible. The complex relationship between mental health and concussion recovery requires further study, with particular attention focused on the role that personality, resilience, family, developmental and environmental factors may play in mental health after paediatric concussion. In-depth clinical interviews and qualitative research designs, largely lacking to date, are needed to extend these quantitative findings and draw out these complex relationships. To date, many studies have excluded children with a history of mental health diagnoses. Given the community prevalence of mental illness among children and adolescents and the potential role that mental health may play in recovery from concussion, this represents an important limitation, which likely skews our current understanding of concussion recovery and its underlying mechanisms. Mental health was predominantly reported by parents, with only a quarter of studies including multiple informants. Given that parents' understanding of concussion may influence their perceptions and attributions of post-injury mental health difficulties,[80] future research should obtain a range of perspectives.

CONCLUSIONS

Our study revealed that children experience elevated mental health difficulties after concussion which can persist several years post-injury. Assessment, prevention and intervention of mental health difficulties after concussion should be integrated into standard concussion management. A range of biopsychosocial factors need to be considered to clarify the nature of post-concussion recovery on an individual basis. Further research is needed to illuminate the mechanisms underlying observed relationships between mental health, PCS and psychosocial factors.

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SUPPLEMENTARY MATERIAL
CONTENTS

SUPPLEMENTARY RESULTS

Methodological Characteristics

Most included studies recruited children through hospitals (*n*=56, 81.2%), including emergency departments (*n*=19, 27.5%), inpatient admissions (*n*=33, 47.8%) and outpatient services (*n*=15, 21.7%). Thirteen studies recruited from both inpatient and outpatient services. The remaining studies recruited participants from community sports organizations and local schools (*n*=2, 2.9%), population cohort (*n*=3, 4.3%), or via existing research databases (*n*=2, 2.9%).

Definitions of concussion were provided by all studies. Four studies explicitly stated that their definition aligned the Berlin Consensus Statement on Concussion in Sport, while the remaining studies employed criteria consistent with this definition or reported outcomes for an uncomplicated concussion subgroup.

Key participant demographics were considered by several studies including socio-economic status (*n*=27), ethnicity (*n*=19), number of previous concussions (*n*=11), family functioning (*n*=5) and parent mental health (*n*=5).

SUPPLEMENTARY TABLES

Supplementary Table 1. Reported mental health outcomes, study characteristics and quality assessment of included studies

Study	N	Design	Setting	Country	Male	Age at Injury, Range, M (SD)	Assessed Timepoints	Report proxy	Mental Health Measures	Main Mental Health Findings	DBC	OCEBM
Albicini et al. (2018)* [1]	Concussion (*n*=65), Orthopaedic Injury (n=43)	Longitudinal, between-subjects, cross-sectional	Hospital, ED	New Zealand	66%	0-17 years, 10.86 (4.87)	12.17 years (5.31) post-injury	Child	CIDI	Children with concussion reported significantly more psychiatric diagnoses than children with orthopaedic injuries with a moderate effect size.	13.5	Level 4
Anderson et al. (2001) [2]	Concussion (*n*=31)	Prospective, longitudinal, between-group	Hospital admissions to neurosurgical ward	Australia	67%	2-12 years, 9.3 (2.9)	6 months post-injury	Parent	RBRI, PIC	Behavioural functioning within the normal range pre- and post-concussion. Results showed slight but non-significant deterioration in behaviour scores post-injury.	16	Level 3
Anderson et al. (2005a) [3]	Concussion (*n*=10), TDC (*n*=26)	A prospective, longitudinal, between group	Hospital admissions to neurosurgical ward	Australia	50%	2-7 years, 4.6 (1.3)	30-months post-injury	Parent	PIC	While mean internalising and somatic symptoms increased over time, no significant differences in internalising problems were observed compared to TDC 30 months-post-concussion.	16	Level 3
Anderson et al. (2005b) [4]	Concussion (*n*=42)	Prospective, longitudinal, between group	Hospital admissions to neurosurgical ward	Australia	64%	3-12.11 years, 8.4 (3.0)	6- and 30-months post-injury	Parent	RBRI, PIC	Although there was some within group variation, post-injury behaviour was within the normal range and remained stable from 6-months to 30-months post-injury.	17.5	Level 3
Anderson et al. (2009) [5]	Concussion (*n*=40)	Retrospective cross-sectional	Hospital admissions to neurosurgical ward	Australia	70%	0-16 years, 10.19 (1.80)	2.5 years post-injury	Medical record	Service engagement	No differences were observed in psychiatric intervention between children with concussion and population data either acutely (17.5%) or in the long term (12.5%).	17.5	Level 3
Anderson et al. (2012a) [6]	Concussion (*n*=20)	Prospective, longitudinal, between group	Admission to paediatric hospital ED or neurosurgery ward	Australia	60%	2-12:11 years, 8.36 (3.08)	10 years post-injury	Parent	Service engagement	Children with concussion showed higher problem behaviors 10-years post injury than expected risk of impairment.	19	Level 3

Study	N	Design	Setting	Country	Male	Age at Injury, Range, M (SD)	Assessed Timepoints	Report proxy	Mental Health Measures	Main Mental Health Findings	DBC	OCEBM
Anderson et al. (2012b) [7]	Concussion (*n*=130)	Prospective, longitudinal, between group	Admission to paediatric hospital ED or neurosurgery ward	Australia	72%	6-14 years, 10.80 (2.42)	Pre-injury, 6 months post-injury	Parent	CBCL	Internalising, externalising and total behaviour problems were not significantly different before and after concussion. Pre-injury ratings significantly predicted post-concussion behavioural functioning.	18	Level 3
Anderson et al. (2020) [8]	Concussion (*n*=256)	Longitudinal prospective cohort study	Paediatric hospital ED	Australia	72%	5-18 years,	2 weeks, 3 months post-injury	Parent	CBCL	Children who recovered within 2 weeks demonstrated fewer internalising problems and lower rates of pre-injury psychiatric diagnoses than children with delayed recovery.	18	Level 3
Antshel et al. (2007)* [9]	Concussion (*n*=31), TDC (*n*=23)	Cross-sectional, between groups	Large urban academic medical center	USA	74%	6-11 years, 9:5 (1:9)	3 and 6 months	Parent & teacher	BASC	Despite similar ratings in behaviour problems 3 months post-injury, parents reported significantly more externalising problems 6 months post-injury than controls, as well as children with positive MRI findings. In the absence of MRI findings, parents were more likely to attribute externalising problems to be within their child's control, rather than attributed to the injury.	15.5	Level 3
Barker-Collo et al. (2007)* [10]	Concussion (*n*=40), Orthopaedic Injury (*n*=14)	Case control	ICU, neurology orthopaedic care units at a regional paediatric hospital	New Zealand	68%	3.8-13 years, 8.54 (3.52)	2-24 months, 7.22 (7.15) post-injury	Parent	CBCL	Behavioural problems fell within the normal range for concussion and control groups. Children with concussion exhibited lower scores on withdrawal, anxiety and depression compared with controls, resulting in a lower score on the internalising and total problem scores.	13.5	Level 3

Study	N	Design	Setting	Country	Male	Age at Injury, Range, M (SD)	Assessed Timepoints	Report proxy	Mental Health Measures	Main Mental Health Findings	DBC	OCEBM
Bellerose et al. (2015)* [11]	Concussion (*n*=51), TDC (*n*=50)	Prospective longitudinal cohort	ED	Canada	51%	1.5-5 years, 3.0 (0.9)	6.51 months, SD=0.83 post-injury	Parent	CBCL	Externalising behaviors were significantly higher in the concussion group than control group both pre-injury and 6 months post-concussion with a moderate effect size.	15	Level 3
Bernard et al. (2017)* [12]	Concussion (*n*=46), TDC (*n*=55)	Prospective longitudinal	ED	Australia	63%	2-12 years 11 months	<72 hours, 1 week, 1 month, 2 months, 3 months post-injury	Parent	CAB-P, CBI	Problematic behaviour significantly increased from pre-morbid levels in the concussion group compared with controls. Higher rates of premorbid post-concussive symptoms and the presence of premorbid learning difficulties were significant predictors of increased behavioural problems over time.	16.5	Level 3
Bloom et al. (2001) [13]	Concussion (*n*=15)	Retrospective exploratory study	Paediatric Hospital	USA	67%	6-15 years, m=9.9 (SD=4.4)	2.2 years post-injury	Child & parent	CDI, PIC, DICA-R	40% youth with concussion developed novel psychiatric disorders, 13.33% developed two or more novel psychiatric disturbances. Mean scores on the PIC-R were within the normal range.	13.5	Level 3
Bohorquez-Montoya 2020* [14]	Concussion (*n*=36), TDC (*n*=15)	Cross-sectional	Concussion clinic and community	USA	42%	14-18 years, 16.20 (1.07)	<3 months, 52 (6.97) days	Child	GAD-7, PHD-9, BSI, SHAPS	Children with delayed recovery after concussion reported more depression symptoms and psychological distress than recovered children and TDC. Anxiety was also significantly higher among children with delayed recovery compared with controls. Anhedonia was significantly higher among children with delayed recovery than recovered children after concussion.	13	Level 3

Study	N	Design	Setting	Country	Male	Age at Injury, Range, M (SD)	Assessed Timepoints	Report proxy	Mental Health Measures	Main Mental Health Findings	DBC	OCEBM
Botchway et al. (2019)* [15]	Concussion (*n*=14), TDC (*n*=13)	Prospective longitudinal design	Neurosurgical ward admissions, tertiary paediatric hospital	Australia	64%	0-12 years, 9.2 (2.9)	20 years post-injury	Child	DASS	High levels of post-concussion pain and anxiety significantly correlated with poorer sleep quality.	18	Level 3
Brooks et al. (2018)* [16]	Concussion (*n*=37), Orthopaedic Injury (*n*=16)	Prospective, multi-center cohort	Research databases	Canada	54%	8-19 years, 12.1 (2.7)	2.7 years post injury	Child & parent	BASC-2	Parents of youth with a history of concussion reported significantly worse anxiety and depression symptoms than parents of children with orthopaedic injury.	16	Level 3
Brooks et al. (2018) [17]	Concussion (*n*=275)	Cross-sectional	ED	Canada	65%	6-18 years, 11.6 (3.1)	4 weeks, 12 weeks post-injury	Parent	CBCL, SDQ	22.9% of children reported psychological distress at 4 weeks post-concussion and 23.2% at 12 weeks post-concussion. 60% of children with a history of anxiety or depression had elevated psychological distress at 4 weeks and 50% at 12 weeks. Among children without a history of anxiety or depression, 19.3% met the criterion for elevated psychological distress at 4 weeks and 20.5% at 12 weeks.	18	Level 3
Brown et al. (2016)* [18]	Concussion (*n*=116), TDC (*n*=5,414)	Prospective longitudinal Study	Three tertiary paediatric hospitals	Australia	69%	6-14 years, 10.44 (2.46)	3 months, 6 months, 12 months, 18 months post-injury	Parent	CHQ-PF50	Children with concussion showed clinically significant general behaviour problems compared with norms (3 months). Means fell within the normal range at subsequent time points (6 months). Older children demonstrated reduced functioning on behavioural and self-esteem subscales, but greater functioning on general behaviour.	14	Level 3

Study	N	Design	Setting	Country	Male	Age at Injury, Range, M (SD)	Assessed Timepoints	Report proxy	Mental Health Measures	Main Mental Health Findings	DBC	OCEBM
Bunt et al. (2020) [19]	Concussion (*n*=491)	Prospective	Specialized concussion clinics	USA	53%	12-18 years, 14.72 (1.64)	8.26 days (SD 5 7.30)	Child	GAD-7, PHQ-8	Females reported significantly higher levels of anxiety and depression in the days after concussion.	15.5	Level 3
Butler et al. (1997) [20]	Concussion (*n*=36)	Retrospective	Two large urban clinics and one large urban private practice	USA	UTD	6-16 years, 8.71 (3.4)	2.07 years post-injury	Parent	PIC-R	50% of children with concussion experience cognitive symptom profiles, while approximately 40% experience internalising symptoms and mild anxiety post-concussion.	12	Level 3
Catale et al. (2009) [21]	Concussion (*n*=15)	Use of a longitudinal design with follow-up assessment	Admissions to neuro-paediatric unit	Belgium	33%	6.7–11.5 years, M=8.3, SD=1.2	1-year post-injury	Parent	CPRS-R	Children's behavioural symptoms before concussion within the normal range for all factors considered. Results showed significantly more impulsive hyperactive symptoms after concussion compared with pre-injury functioning.	12	Level 3
Catroppa et al. (2012)* [22]	Concussion (*n*=40), Matched TCD (*n*=19)	Prospective longitudinal design	Hospital admission, tertiary paediatric hospital	Australia	43%	1.17-8.00 years, 4.81 (1.92)	10 years, 10.54 (1.57)	Parent	PIC, BASC	Externalising problems were significantly higher for the concussion group than for the control group. The concussion group showed a trend towards a higher percentage impaired for internalising problems and total behavioural symptoms.	17	Level 3
Crichton et al. (2017) [23]	Concussion (*n*=27)	Prospective longitudinal design	Hospital ED & ICU	Australia, Canada	85%	8-18 years, 13.3 (2.4)	6 weeks post-injury	Parent	CDI-2-P, CDI-2-SR, SCAS	Parent ratings of child depression was significantly associated with severe levels of fatigue.	18.5	Level 3

Study	N	Design	Setting	Country	Male	Age at Injury, Range, M (SD)	Assessed Timepoints	Report proxy	Mental Health Measures	Main Mental Health Findings	DBC	OCEBM
Crowe et al. (2012)* [24]	Concussion (*n*=20), TDC (*n*=27)	Cohort	Tertiary paediatric hospital ED and ICU	Australia	55%	1-35 months, 17.7 (10.7)	40 months post-injury	Parent	CBCL	Medium effect sizes were identified between the control and concussion group for emotionally reactive, withdrawn, and attention problems.	15	Level 3
Crowe et al. (2016) [25]	Concussion (*n*=10)	Prospective, longitudinal design	Local schools and sporting groups	Australia	70%	10-17 years, 14.6 (1.7)	30 days post-injury	Parent	CHQ	25.0% of parents rated their child as demonstrating post-concussion behaviour problems. Significant concerns were reported for 37.5% of cases for both mental health and family cohesion.	17.5	Level 2
Ellis et al. (2015) [26]	Concussion (*n*=174)	Retrospective chart review	Concussion clinic	Canada	62%	<19 years, 14.22 (2.34)	>1 month post-injury	Child	Psychiatric diagnoses	11.5% of children met the criteria for a psychiatric diagnoses post-concussion, including 8.0% with novel psychiatric diagnoses, 1.1% with isolated suicidal ideation, and 2.3% with worsening symptoms of a preinjury psychiatric disorder. Female sex, higher acute PCSS score, higher emotional PCSS index, preinjury psychiatric history, and family history of psychiatric illness were significantly associated with psychiatric outcomes.	14	Level 3
Fischer et al. (2018)* [27]	Concussion (*n*=11), Orthopaedic Injury (*n*=24), TDC (*n*=27)	Prospective longitudinal	Level 1 Paediatric Trauma centre	USA	64%	8-15 years, 12.2 (2.4)	Baseline, 6 months, 12 months post-injury	Parent	CBCL	Internalising problems were significantly higher after concussion compared with typically developing controls. No group differences in externalising problems observed between groups.	15	Level 3
Study	**N**	**Design**	**Setting**	**Country**	**Male**	**Age at Injury,**	**Assessed Timepoints**	**Report proxy**	**Mental Health**	**Main Mental Health Findings**	**DBC**	**OCEBM**

						Range, M (SD)			Measures			
Fletcher et al. (1990) [28]	Concussion (*n*=13)	Longitudinal	Paediatric neurosurgery services of two major university trauma hospitals	USA	62%	3-15 years, 8.6 (4.6)	Time of injury, 6 months, 12 months post-injury	Parent	CBCL	Scores on all scales were within the average range. No significant differences were found between scores at baseline, 6-months and 12-months post-concussion. No significant associations observed between CBCL scores and 75 cognitive variables.	16.5	Level 3
Gagner et al. (2018)* [29]	Concussion (*n*=86), TDC (*n*=81), Orthopaedic Injury (*n*=62)	Prospective longitudinal cohort	Tertiary care, paediatric ED	Canada	53%	1.3-5 years, 3.63 (0.98)	6 months post-injury	Parent	CBCL	There were significantly higher ratings of internalising and externalising behaviors in the concussion group than both control groups. In the concussion group, 38.4% of children had at least one clinically elevated score, compared with 25.8% in the orthopaedic injury group and 18.5% in the TDC group. There was a significant difference in this proportion between concussion and TDC groups, but not orthopaedic injury group.	18	Level 3
Gagner et al. (2020)* [30]	Concussion (*n*=85), TDC (*n*=82), Orthopaedic Injury (*n*=59)	Prospective longitudinal cohort	Tertiary care, paediatric ED	Canada	53%	1.3-5 years, 3.63 (0.98)	6, 18 and 30 months post-injury	Parent	CBCL	Children had significantly higher internalising and externalising problems 6 months post-injury compared with TDC, but not the orthopaedic injury group.	19	Level 3

Study	N	Design	Setting	Country	Male	Age at Injury, Range, M (SD)	Assessed Timepoints	Report proxy	Mental Health Measures	Main Mental Health Findings	DBC	OCEBM
Gornall et al. (2019)* [31]	Concussion (*n*=231), Orthopaedic Injury (*n*=11)	Prospective longitudinal cohort	Tertiary paediatric hospital ED	Australia	73%	5-<18 years, 11.7 years (3.1)	2 weeks, 3 months post-injury	Parent	CBCL	Children with concussion showed a significant improvement in behavioural functioning from 2-weeks to 3-months post-injury. As age increased, females were at increased risk for experiencing ongoing internalising problems 3 months after concussion.	18	Level 3
Gray et al. (2007) [32]	Concussion (*n*=22), Orthopaedic Injury (*n*=19)	Qualitative	Hospital ED	USA	59%	7-16 years, 10.00 (2.64)	0.88 years (0.28) post-injury	Parent	CBCL qualitative comments	Parents who endorsed high levels of after their child's concussion were most concerned about their child's poor school performance, lack of friends, inability to control angry feelings, apathy and problems with PTSD.	-	-
Guo et al. (2017) [33]	Concussion (*n*=105)	Prospective	Paediatric hospital admission	Australia	73%	6-14 years, 10.82 (2.44)	6 months post-injury	Child	CAPS-CA	Female sex, sustained attention and working memory functioning predicted poor PTSD outcomes 6-months post-concussion.	17	Level 3
Ho et al. (2018; 2020) [34, 35]	Concussion (*n*=30)	Single-site, cross-sectional investigation	Paediatric hospital, rehabilitation clinics, physician offices	Canada	33%	10-17 years, 13.8 (2.6)	5-8 weeks post-injury	Child & parent	CDI	36.7% of children experienced elevated depression following concussion.	15.5	Level 3

Study	N	Design	Setting	Country	Male	Age at Injury, Range, M (SD)	Assessed Timepoints	Report proxy	Mental Health Measures	Main Mental Health Findings	DBC	OCEBM
Kaldoja et al. (2012)* [36]	Concussion (*n*=35), matched TDC (*n*=70)	Prospective case-controlled study	Hospital	Estonia	63%	<5:5 years, 2.84 (1.66)	Pre-injury, follow-up 9 months post-injury	Parent	ASQ-SE	Children with concussion showed more pre-injury social-emotional difficulties compared to matched TDC. At follow-up, children with concussion showed more general social-emotional problems compared to TDC, with worsening social interaction problems over time.	16	Level 4
Keenan et al. (2018)* [37]	Concussion (*n*=144), Orthopaedic Injury (*n*=133)	Prospective cohort	Two level 1 paediatric trauma centres	USA	61%	2.5-15 years, 9.1 (4.3)	Pre-injury, 3 months, 12 months post-injury	Parent	CBCL, SDQ	Children with concussion had significantly higher scores on affective, anxiety, and ADHD subscales compared with the orthopaedic injury group. Children with concussion had decreasing symptoms over time. School-age children had high ADHD and affective symptoms scores, while pre-schoolers showed increasing symptoms over time. Females had significantly poorer functioning on all CBCL outcomes. A positive family environment was associated with better outcomes on all CBCL scales.	18	Level 3
Kenardy et al. (2012) [38]	Concussion (*n*=166)	Prospective longitudinal	Three tertiary paediatric hospitals	Australia	66%	6-15 years, 10.80 (2.42)	Pre-injury, 2 months, 3, 6, 12 months post-injury	Child	CBCL, CAPS-CA, CHQ-PF50	8% of the concussion group met PTSD diagnostic criteria. Children with PTSD showed significantly poorer psychosocial outcomes throughout the study period.	18	Level 3

Study	N	Design	Setting	Country	Male	Age at Injury, Range, M (SD)	Assessed Timepoints	Report proxy	Mental Health Measures	Main Mental Health Findings	DBC	OCEBM
Konigs et al. (2015)* [39]	Concussion (*n*=24), TDC (*n*=52)	Retrospective recruitment from consecutive cohort	Three university-affiliated level I trauma centres	The Netherlands	46%	6-13 years, 7.1 (2.4)	1.7 years post-injury	Parent & Teacher	CBCL	Children with concussion had more internalising problems according to teacher, but not parent report. No significant differences in internalising, externalising or attention problems were observed according to either parent and teacher report.	17	Level 3
Konigs et al. (2016)* [40]	Concussion (*n*=24), TDC (*n*=52)	Retrospective recruitment from consecutive cohort	Three university-affiliated level I trauma centres	The Netherlands	46%	6-13 years, 7.1 (2.4)	1.7 years post-injury	Parent & Teacher	CBCL	Internalising behaviour problems were significantly higher among children with concussion according to teachers. Nil other significant differences observed in internalising, externalising or attention problems according to either parent and teacher report.	18	Level 3
Kontos et al. (2012) [41]	Concussion (*n*=75)	Pretest, multiple posttest, repeated-measures	Institutions involved in concussion surveillance program	USA	74%	High School <18 years, 15.74 (1.28)	2-14 days post-injury	Child	BDI-II	Athletes reported significantly higher levels of depression symptoms from baseline at 2 days, 7 days, and 14 days post-concussion. There were no significant between-subject effects for age and sex on depression.	13	Level 3
Laliberté Durish et al. (2018)* [42]	Concussion (*n*=49), Orthopaedic Injury (*n*=26)	Cross-sectional	Research databases consisting of patients recruited from various clinics at a paediatric hospital	Canada	47%	8-18 years, 11.68 (2.83)	2.7 years (m=33.40 months, SD=19.59)	Child & parent	BASC-2, SDQ	Significantly more general behavioural problems, higher levels of anxiety and depression, and poorer quality of life reported in the concussion group compared with controls. Higher levels of resilience were associated with better behavioural functioning, fewer self-reported depressive symptoms and better quality of life.	15	Level 3

Study	N	Design	Setting	Country	Male	Age at Injury, Range, M (SD)	Assessed Timepoints	Report proxy	Mental Health Measures	Main Mental Health Findings	DBC	OCEBM
Lalonde et al. (2020) [43]	Concussion (*n*=68), TDC (*n*=76) Orthopaedic Injury (*n*=49)	Prospective longitudinal cohort	Urban tertiary care paediatric ED	Canada	56%	1.3-5 years, 3.49 (0.95)	6 months post-injury	Parent	CBCL	Child behaviour was not associated with parent-child interactions after concussion on any subscale. Socioeconomic status, child post-concussive symptoms, and child sleep problems significantly contributed to parent– child interactions.	17	Level 3
Luis et al. (2002)* [44]	Concussion (*n*=42) Orthopaedic Injury (*n*=35)	Prospective cohort	General Hospital admissions	USA	67%	6-15 years, 10.5 (3.3)	6 months post-injury	Child	DISC-IV, SRRQ	Children with concussion had significantly higher rates of novel diagnoses compared to the control group. Post-injury stress level and injury severity significantly predicted subsequent disorders.	14.5	Level 3
Massagli et al. (2004)* [45]	Concussion (*n*=490) TDC (*n*=1470)	Prospective cohort	ED (*n*=279), outpatient (*n*=191) and hospital settings (*n*=20)	USA	62%	<15 years, 0-4 years (n=129), 5-9 (n=161), 10-14 (n=200)	0-12 months, 12-24 months, 24-36 months post-injury	Medical records	Psychiatric Diagnoses	26% of children without a pre-morbid psychiatric history were diagnosed with a psychiatric illness after concussion. Evidence of any psychiatric illness during the 3-year follow-up was significantly higher among children with no psychiatric history after concussion compared with the control group. Psychiatric illness was estimated to occur in 55% of concussion patients and in 63% of controls (*p*=0.63) who had a prior psychiatric history.	15.5	Level 3

| Study | N | Design | Setting | Country | Male | Age at Injury, | Assessed Timepoints | Report proxy | Mental Health | Main Mental Health Findings | DBC | OCEBM |

						Range, M (SD)		Measures				
McKinlay et al. (2002)* [46]	Concussion (*n*=28) TDC (*n*=788)	Inception cohort	All hospital births in the region; inpatient and outpatient treated concussion	New Zealand	72%	<10 years old	Age 10, 11, 12, 13 (1-13 years post-injury)	Mother & teacher	RBRS, CBRS	Concussion inpatients showed increased attention and conduct problems than controls with medium to large effect sizes. After accounting for several demographic, family, and pre-injury characteristics, the inpatient but not the outpatient group displayed increased hyperactivity/inattention and conduct disorder between ages 10 to 13. Psychosocial deficits were more prevalent in the inpatient subgroup injured before age 5.	17.5	Level 2
McKinlay et al. (2009)* [47]	Concussion (*n*=76) TDC (*n*=839)	Inception cohort	All hospital births in the region; inpatient and outpatient treated concussion	New Zealand	53%	<5 years old	At age 14 to 16 years	Child, mother & teacher	DISC, SRED, RBPC	At age 14 to 16 years, children who had been hospitalized for concussion sustained in preschool years were significantly more likely to show symptoms of attention deficit/ hyperactivity disorder (OR=4.2), conduct disorder/oppositional defiant disorder (OR=6.2), substance abuse (OR=3.6), and mood disorder (OR=3.1) but not anxiety disorder.	17.5	Level 2
McKinlay et al. (2010)* [48]	Concussion (*n*=81), TDC (*n*=831), Orthopaedic injury (*n*=20)	Inception cohort	All hospital births in the region; inpatient and outpatient treated concussion	New Zealand	51%	<10 years old	Age 10, 11, 12, 13 (1-13 years post-injury)	Mother & teacher	RBRS, CBRS	Higher rates of ADHD, oppositional disorder and conduct disorder problems among children hospitalized for concussion, compared to children who attended outpatient services post-concussion and control group. The inpatient concussion group showed increasing behavioural difficulties over time.	16	Level 2

Study	N	Design	Setting	Country	Male	Age at Injury, Range, M (SD)	Assessed Timepoints	Report proxy	Mental Health Measures	Main Mental Health Findings	DBC	OCEBM
McKinlay et al. (2014)* [49]	Concussion (*n*=58), Orthopaedic injury (*n*=38)	Longitudinal cohort	Audit of neurosurgical files, ED and admission records, and community	New Zealand	53%	0-17 years, 7.1 (4.0)	>5 years post-injury	Child report	EBS	Children with concussion reported more problems with malevolent aggression, but not social anxiety or self-esteem compared with orthopaedic controls.	15	Level 3
O'Connor et al. (2012)* [50]	Concussion (*n*=120) Orthopaedic Injury (*n*=39)	Prospective cohort	One Level 1 trauma centre, four Level 3 or 4 trauma centres and four non-trauma centre hospitals	USA	71%	14-17 years, 15.88 (0.93)	5 weeks, 3 months, 12 months and 24 months post-injury	Child & parent	PHQ, UCLA PTSD Reaction Index for DSM-IV-R	Children with concussion reported significantly worse PTSD symptoms across time compared to the control group. Greater levels of PTSD symptoms were associated with poorer school and physical functioning. Greater depressive symptoms were associated with poorer school functioning.	18	Level 3
Plourde et al. (2018)* [51]	Concussion (*n*=48) Orthopaedic Injury (*n*=27)	Cross-sectional	Tertiary care paediatric hospital	Canada	46%	8-19 years, 11.61 (2.72)	>12 months, 35.92 months post-injury	Child	BASC-2, SDQ	No significant differences were observed on long-term psychosocial functioning between groups. Pre-existing mood concerns and attention problems significantly predicted psychosocial adjustment post-concussion.	17	Level 3
Plourde et al. (2019) [52]	Concussion (*n*=33)	Cross-sectional	ED	Canada	49%	9.5-18.6 years, 4.9 (2.4)	15.5-31.2 months post-injury, 22.8 (5.6),	Child & parent	BASC-2, C-DISC-IC	18.2% of participants and parents reported at least mild post-concussion anxiety, while 6.5% met diagnostic criteria for generalized anxiety disorder. 9.1-12.1% reported depressive symptoms, with 6.5% meeting criteria for a major depressive episode.	14.5	Level 3

Study	N	Design	Setting	Country	Male	Age at Injury, Range, M (SD)	Assessed Timepoints	Report proxy	Mental Health Measures	Main Mental Health Findings	DBC	OCEBM
Renstrom et al. (2012)* [53]	Concussion (*n*=13), TDC (*n*=229)	Case-control retrospective design	University Hospital Department of Paediatrics, neurosurgery, neurorehabilitation, surgery & orthopaedics	Sweden	60%	7-18 years, 12.9 years (3.1)	4.7–8.6 years post-injury, 6.8 (1.1)	Child	SF-36	The concussion group showed lower but non-significant mental health outcomes compared with the control group. Nearly half of the participants with concussion reported that their life situation was negatively influenced by the concussion including problems with finding jobs, affected school results and difficulties in everyday living.	12	Level 4
Rockhill et al. (2010)* [54]	Concussion (*n*=490), TDC (*n*=1470)	Prospective cohort	Large HMO	USA	62%	<15 years, 0-4 years (n=129), 5-9 (n=161), 10-14 (n=200)	3 years post-injury	Healthcare provider	ICD-9 Codes	28% of children experienced psychological distress in the 3 years after concussion, compared with 18% of TDC (OR=1.71). Presence of psychological distress was also associated with increased costs in all categories examined and was associated with an approximate doubling of mean total costs.	17.5	Level 3
Rosema et al. (2015)* [55]	Concussion (*n*=13) TDC (*n*=20)	Prospective, longitudinal	Neurosurgical Ward, tertiary paediatric hospital	Australia	59%	1-7 years 11 months, 4.59 (1.64)	Acute, 6 months, 5, 10- and 16-years post-injury	Parent	PIC, ABCL, PIC	The concussion group showed significantly higher levels of internalising and externalising symptoms between six months and 10 years post-injury. Mean levels internalising and externalising symptoms for both groups fell within the average range.	17	Level 3

| Study | N | Design | Setting | Country | Male | Age at Injury, | Assessed Timepoints | Report proxy | Mental Health | Main Mental Health Findings | DBC | OCEBM |

						Range, M (SD)			Measures			
Ryan et al. (2015) [56]	Concussion (*n*=15)	Longitudinal prospective	Paediatric hospital emergency department	Australia	53%	1-12 years, 7.89 (3.68)	16 years post-injury	Significa nt other	ABCL	20% of the concussion group showed clinical or subthreshold levels of externalising symptoms 16 years post-injury. Clinical or subthreshold levels of externalising problems were not associated with injury severity but were, instead equally apparent across young adults with TBI of all severity levels.	18	Level 3
Ryan et al. (2016)* [57]	Concussion (*n*=13) TDC (*n*=33)	Longitudinal	Hospital	Australia	75%	5.3-15.4 years, 10.69 (2.35)	24 months post-injury	Parent	CBCL	No significant differences observed between concussion and TDC groups on total behaviour problems.	15	Level 3
Ryan et al. (2019) [58]	Concussion (*n*=15)	Prospective cohort	Hospital admissions	Australia	53%	1-12 years, 7.23 (3.5)	15 years post-injury	Child	GHQ	Depression symptoms post-injury predicted psychological quality of life 15 years postinjury.	18	Level 3
Sariaslan et al. (2016) [59]	Concussion (*n*=80,676), TDC (*n*=1,039, 180)	Inception cohort	Population Cohort	Sweden	61%	0-25 years, 12.2 (0.02)	Lifetime prevalence post-injury	Clinician	Hospital records	Risk of psychiatric visit and psychiatric hospitalization were 31% and 52% higher in the concussion group compared with family members who did not sustain a TBI and adjusting for sex, birth order, birth year, individual and parental education, income, parental lifetime criminal and psychiatric histories and maternal single status	18	Level 2
Study	**N**	**Design**	**Setting**	**Country**	**Male**	**Age at Injury, Range, M (SD)**	**Assessed Timepoints**	**Report proxy**	**Mental Health Measures**	**Main Mental Health Findings**	**DBC**	**OCEBM**

Schachar et al. (2004)* [60]	Concussion (*n*=65) TDC (*n*=57)	Historical cohort	Several large, urban paediatric hospitals	USA	59%	0.4-13.7 years, 6.1 (3.3)	>2 years post-injury, 5.1 (2.1)	Parent & Teacher	SDI	Secondary ADHD symptoms and diagnoses significantly higher in concussion group compared with controls. No significant differences in anxiety symptoms or diagnoses post-concussion.	11.5	Level 3
Scott et al. (2015)* [61]	Concussion (*n*=61) Orthopaedic injury (*n*=43)	Cohort	Audit of neurosurgery files, ED admissions and community notices	New Zealand	54%	1-17 years, 7.1 (4.0)	15.1 (4.7) years post-injury	Child	CIDI	The concussion group showed significantly more anxiety disorder diagnoses and substance abuse disorders compared with controls. Depression and offending were twice as prevalent in the concussion group. Anxiety disorders were three times more prevalent in females, whilst offending behaviour and substance abuse/dependence was 4-5 times higher in males after concussion.	13.5	Level 3
Smyth et al. (2014) [62]	Concussion (*n*=89)	Cross-sectional	Research databases	Canada	65%	0-18 years, 13.8 (3.2)	1.73 years post-injury	Child	CDI	Depression scores in the symptomatic and asymptomatic concussion groups did not differ significantly. 3% of children with concussion had clinically significant depression symptoms. Age and stressful life events showed a significant difference between groups. After controlling for the effects of age, the stressful life events score was a significant predictor of being symptomatic after concussion.	15	Level 3
Study	**N**	**Design**	**Setting**	**Country**	**Male**	**Age at Injury, Range, M (SD)**	**Assessed Timepoints**	**Report proxy**	**Mental Health Measures**	**Main Mental Health Findings**	**DBC**	**OCEBM**

Study	N	Design	Setting	Country	Male	Age at Injury, Range, M (SD)	Assessed Timepoints	Report proxy	Mental Health Measures	Main Mental Health Findings	DBC	OCEBM
Stojanovski et al. (2019)* [63]	Concussion (*n*=418) Orthopaedic Injury (*n*=3193)	Retrospective population cohort	Population Cohort	USA	61%	8-22 years, 14.4 (3.4)	UTD	Child & parent	GOASSESS	Children with concussion had a significantly higher ADHD symptom severity score compared with children with other injuries (p=0.002).	14	Level 2
Taylor et al. (2015)* [64]	Concussion (*n*=56) Orthopaedic injury (*n*=41)	Cohort	Audit of ED admissions, neuro-surgery files, community recruitment	New Zealand	50%	0-18 years, 6.7 (4.0)	>5 years post-injury	Child	DSMIV-TR Structured Interview	Small, non-significant increase in Major Depressive Disorder diagnoses were observed in the concussion group compared with the orthopaedic control group.	16	Level 3
Theadom et al. (2016)* [65]	Concussion (*n*=68) TCD (*n*=68)	Longitudinal study with an embedded case control study	Hospital & ambulance records, school and sports clubs, general practitioner, allied health service referrals, and self-referral	New Zealand	60%	8-16 years, 10.5 (2.1)	1-year post-injury	Child & parent	BASC-2	Significantly higher internalising and externalising behaviour problems 1-year after concussion, compared with the control group. Sleep quality was significantly associated with externalising behaviour (p<0.01) while age, sleep quantity and pain were significantly associated with internalising behaviour (p<0.01 for all comparisons).	16	Level 2
Truss et al. (2017) [66]	Concussion (*n*=120)	Prospective longitudinal cohort	Paediatric hospital emergency department	Australia	63%	5-18 years, 12.0 (2.4)	2 weeks, 1 month, 3 months post-injury	Child	CPSS	16% of children had clinically significant post-traumatic symptoms 2-weeks post-concussion, declining to 10% at 1 month and 6% at 3 months post-injury. Group-based trajectory modelling identified three trajectories of post-traumatic stress symptoms post-concussion ‘‘resilient’’ (70%); ‘‘recovering” (25%) and ‘‘chronic symptomatology” (5%).	13.5	Level 3

Valovich McLeod et al. (2017) [67]	Concussion (*n*=12)	Qualitative	Secondary Schools	USA	67%	13-18 years, 15.7 (1.7)	13-20 days, follow-up in first 2 months post-injury	Child	Qualitative semi-structured interview	Participants reported increased emotional symptoms, including irritability, sadness, depression, and anxiousness post-concussion, and felt that this affected their school and social roles. Participants described trying to minimize or mask concussion symptoms to avoid being viewed differently by peers.	-	-
Wilmoth et al. (2019) [68]	Concussion (*n*=141)	Prospective	Outpatient clinics participating in regional concussion registry	USA	54%	12-18 years, 15.0 (1.6)	2 weeks, 3 months post-injury	Child	GAD-7, PHQ	The GAD-7 significantly predicted delayed recovery, with a 1.4-fold increased risk for every point.	14	Level 3
Yang et al. (2016)* [69]	Concussion (*n*=3,605), TDC (*n*=41,664), OI (*n*=2,179)	Inception cohort	Population cohort	Taiwan	60%	≤12 years, 5:7 (3:4)	9-year cumulative incidence, median=4.5 8 years post-injury	Clinician	Diagnosis of ADHD	Children with concussion had a 1.3-fold increased risk of ADHD (95% CI = 1.10, 1.53)	17.5	Level 2

*Study included in meta-analysis.

Abbreviations: Ages and Stages Questionnaire – Social and Emotional Index (ASQ-SE); Behaviour Assessment System for Children (BASC); Brief Symptom Inventory (BSI); Child Behaviour Checklist (CBCL); Child Depression Inventory (CDI); Child Health Questionnaire (CHQ); Child PTSD Symptom Scale (CPSS); Composite International Diagnostic Interview (CIDI); Clinician-Administered PTSD Scale (CAPS-CA); Connors Behaviour Rating Scale (CBRS); Depression, Anxiety and Stress Scale (DASS); Downs and Black Criteria (DBC); Diagnostic Interview Schedule for Children (DISC); Diagnostic Interview for Children and Adolescents-Revised (DICA-R); Emergency Department (ED); Generalized Anxiety Disorder Screener (GAD-7); International Classification of Diseases, Ninth Edition (ICD-9); Patient Health Questionnaire (PHQ); Personality Inventory for Children (PIC); Snaith-Hamilton Pleasure Scale (SHAPS); Self-Report Early Delinquency scale (SRED); Social Readjustment Rating Questionnaire (SRRQ); Revised Behaviour Problems Checklist (RBPC); Rowe Behavioural Rating Inventory (RBRI); Rutter Children Behaviour Questionnaire (RCBQ); Short Form 36 Health Survey (SF-36); Spence Anxiety Scales (SAS); Spence Children's Anxiety Scale (SCAS); and Survey Diagnostic Inventory (SDI); Typically developing control (TDC).

Supplementary Table 2. Subgroup analyses of internalising and externalising difficulties after paediatric concussion

	Persisting			Chronic		
	Q	*df*	*p*	*Q*	*df*	*p*
Internalising						
OCEBM	0.31	1	0.57	7.15	2	0.03*
Data type	0.95	2	0.62	8.87	2	0.01*
Control group	0.26	2	0.88	4.2	2	0.12
Pre-injury psychiatric exclusion	0.43	1	0.51	0.18	1	0.67
Measure type	4.98	2	0.08	1.18	2	0.55
Externalising						
OCEBM	0.83	1	0.36	1.35	1	0.24
Data type	4.08	2	0.12	1.29	2	0.53
Control group	2.30	3	0.51	1.01	2	0.60
Pre-injury psychiatric exclusion	0.72	1	0.40	0.43	1	0.51
Measure type	2.51	1	0.11	7.66	2	0.02*

Supplementary Table 3. Meta-regression of internalising and externalising difficulties after paediatric concussion

	Persisting			Chronic		
	R^2	*F*	*p*	R^2	*F*	*p*
Internalising						
Mean age (years)	0.00	0.06	0.81	0.00	0.36	0.56
Sex (% male)	0.00	0.06	0.81	0.06	1.25	0.29
Pre-injury mental health	0.16	0.96	0.36	-	-	-
Pre-injury psychiatric exclusion	0.00	0.48	0.50	0.00	0.41	0.53
DBC	0.00	0.08	0.79	0.08	1.52	0.24
Externalising						
Mean age (years)	0.00	0.14	0.72	0.05	1.72	0.22
Sex (% male)	0.00	0.38	0.55	0.00	0.84	0.38
Pre-injury mental health	-	-	-	-	-	-
Pre-injury psychiatric exclusion	0.08	1.36	0.33	0.00	0.29	0.60
DBC	0.00	0.00	0.99	0.00	0.97	0.35

Supplementary Table 4. Search strategy for Medline.

Set	*Search Statement*
1.	brain injuries/ or brain injuries, traumatic/ or brain concussion/
2.	exp Head Injuries, Closed/
3.	concuss*.tw,kf.
4.	((mild or minor) adj3 (brain or traumatic or tbi)).tw,kf.
5.	mtbi.tw,kf.
6.	1 or 2 or 3 or 4 or 5
7.	mood disorders/ or mental disorders/ or mental health/ or child behaviour disorders/ or conversion disorder/ or psychological trauma/ or stress disorders, post-traumatic/ or stress disorders, traumatic, acute/ or "Quality of Life"/
8.	anxiety disorders/ or anxiety/
9.	(anxious or anhedonia or apathy or shy* or (social adj adjustment) or (social adj isolation) or (psychological adj stress) or depress* or (affective adj symptom*) or (emotional adj adjustment) or melanchol* or internali#ing or internali#e*).tw,kf.
10.	(mental adj illness).tw,kf.
11.	depressive disorder/ or depression/ or depressive disorder, major/
12.	exp "attention deficit and disruptive behaviour disorders"/
13.	7 or 8 or 9 or 10 or 11 or 12
14.	(boy*1 or girl*1 or child* or adolescen* or juvenile or teen* or youth*1 or pediatric* or paediatric* or preschool or pre-school or infant).af.
15.	6 and 13 and 14
16.	limit 15 to (case reports or comment or editorial or letter or "review")
17.	15 not 16
18.	exp animals/ not human*.sh.
19.	17 not 18
20.	limit 19 to (english language and yr="1980 -Current")

Supplementary Table 5. Search strategy for Embase & Embase Classic.

Set	*Search Statement*
1.	concussion/ or brain concussion/ or traumatic brain injury/ or brain injury/ or acquired brain injury/
2.	((closed adj head adj injur*) or concuss* or mtbi).tw,kw,dq.
3.	((mild or minor) adj3 (brain or traumatic or tbi)).tw,kw,dq.
4.	1 or 2 or 3
5.	minor depression/ or "mixed anxiety and depression"/ or depression assessment/ or depression/ or major depression/
6.	anxiety disorder/ or anxiety/ or posttraumatic stress disorder/ or psychotrauma/
7.	mood disorder/ or mental health/ or "psychological well-being"/ or mental disease/ or "quality of life"/
8.	(anxious or anhedonia or apathy or shy* or (social adj adjustment) or (social adj isolation) or (psychological adj stress) or depress* or (affective adj symptom*) or (emotional adj adjustment) or melanchol* or internali#ing or internali#e* or externali#ing or externali#e).tw,kw,dq.
9.	(mental adj illness).tw,kw,dq.
10.	attention deficit disorder/ or behavior disorder/
11.	somatoform disorder/ or conversion disorder/
12.	5 or 6 or 7 or 8 or 9 or 10 or 11
13.	(boy*1 or girl*1 or child* or adolescen* or juvenile* or teen* or youth*1 or paediatric* or pediatric* or preschool or pre-school or infant*).af.
14.	4 and 12 and 13
15.	adolescent depression/
16.	4 and 15
17.	14 or 16
18.	limit 17 to (editorial or letter or "review")
19.	17 not 18
20.	exp animal/ not human*.sh.
21.	19 not 20
22.	(depressed adj1 (skull or fracture)).tw,kw,dq.
23.	21 not 22
24.	limit 23 to (english language and yr="1980-Current")

Supplementary Table 6. Search strategy for PsycInfo

Set	*Search Statement*
1.	Brain Concussion/ or Traumatic Brain Injury/ or head injury/ or brain injury/
2.	(concuss* or (closed adj head adj injur*)).ti,ab,id.
3.	((mild or minor) adj3 (brain or traumatic or tbi)).ti,ab,id.
4.	mtbi.ti,ab,id.
5.	1 or 2 or 3 or 4
6.	affective disorders/ or mental disorders/ or adjustment/ or emotional disturbances/ or emotional states/ or coping behavior/ or behavior problems/ or somatoform disorders/ or conversion disorder/ or emotional disturbances/ or Posttraumatic Stress Disorder/ or Emotional Trauma/ or Psychological Stress/ or Attention Deficit Disorder/ or "well being"/ or "quality of life"/
7.	internalization/ or externalization/
8.	MAJOR DEPRESSION/ or "DEPRESSION (EMOTION)"/
9.	ANXIETY DISORDERS/ or ANXIETY/
10.	(anxious or anhedonia or apathy or shy* or (social adj adjustment) or (social adj isolation) or (psychological adj stress) or depress* or (affective adj symptom*) or (emotional adj adjustment) or melanchol* or internali#ing or internali#e* or externali#ing or externali#e*).ti,ab,id.
11.	6 or 7 or 8 or 9 or 10
12.	(boy*1 or girl*1 or child* or adolescen* or juvenile* or teen* or youth*1 or paediatric* or pediatric* or preschool or pre-school or infan*).af.
13.	5 and 11 and 12
14.	limit 13 to ("comment/reply" or editorial or letter or review-book or review-media or reviews)
15.	13 not 14
16.	exp animals/ not human*.sh.
17.	15 not 16
18.	(depressed adj1 (skull or fracture)).ti,ab,id.
19.	17 not 18
20.	limit 19 to (english language and yr="2020 -Current")

Supplementary Table 7. Articles retrieved by database

Database	*Articles Retrieved*
OVID - MEDLINE	1,628
OVID - EMBASE	3,203
OVID - PsycINFO	1,903
EBSCO - CINAHL	273
EBSCO - SPORTDiscus	19
Scopus	4,518
PubMed	739
Total	12,283

SUPPLEMENTARY FIGURE LEGENDS

Figure 1. Standard mean difference of acute, persisting, and chronic internalising problems after paediatric concussion omitting outliers.

Figure 2. Standard mean difference of acute, persisting, and chronic externalising problems after paediatric concussion omitting outliers.

Figure 3. Standard mean difference of acute, persisting, and chronic total problems after paediatric concussion omitting outliers.

Figure 4. Persisting and chronic internalising problems after paediatric concussion by design.

Figure 5. Persisting and chronic externalising problems after paediatric concussion by design.

Figure 6. Persisting and chronic internalising problems after paediatric concussion by respondent.

Figure 7. Persisting and chronic externalising problems after paediatric concussion by respondent.

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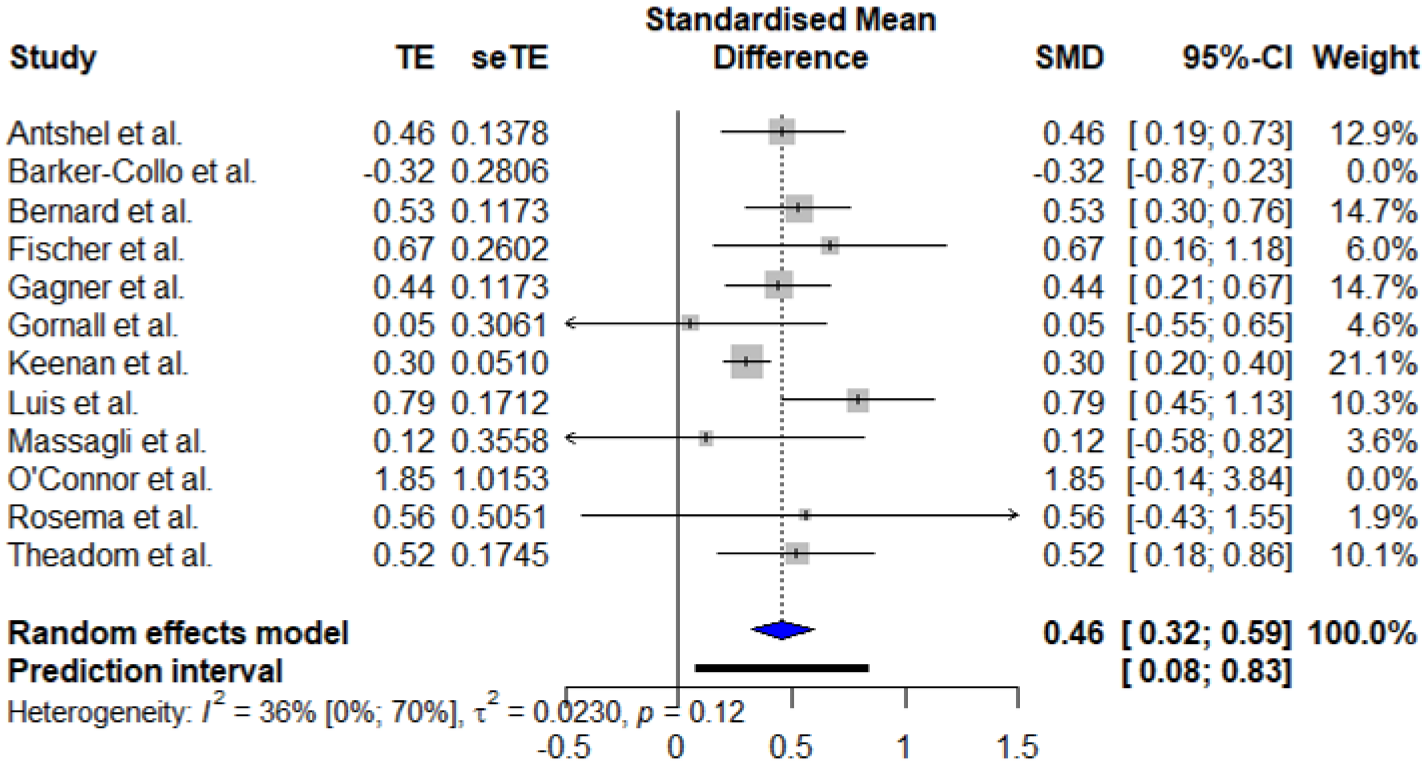
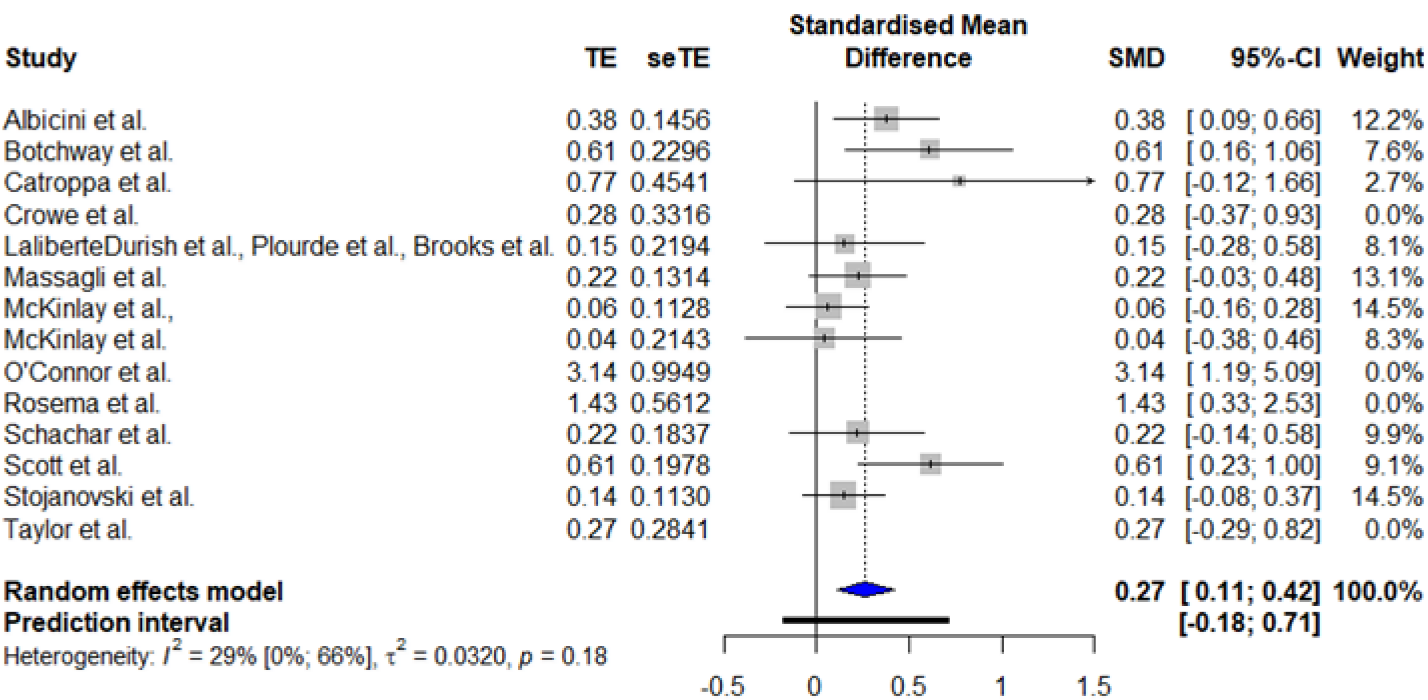
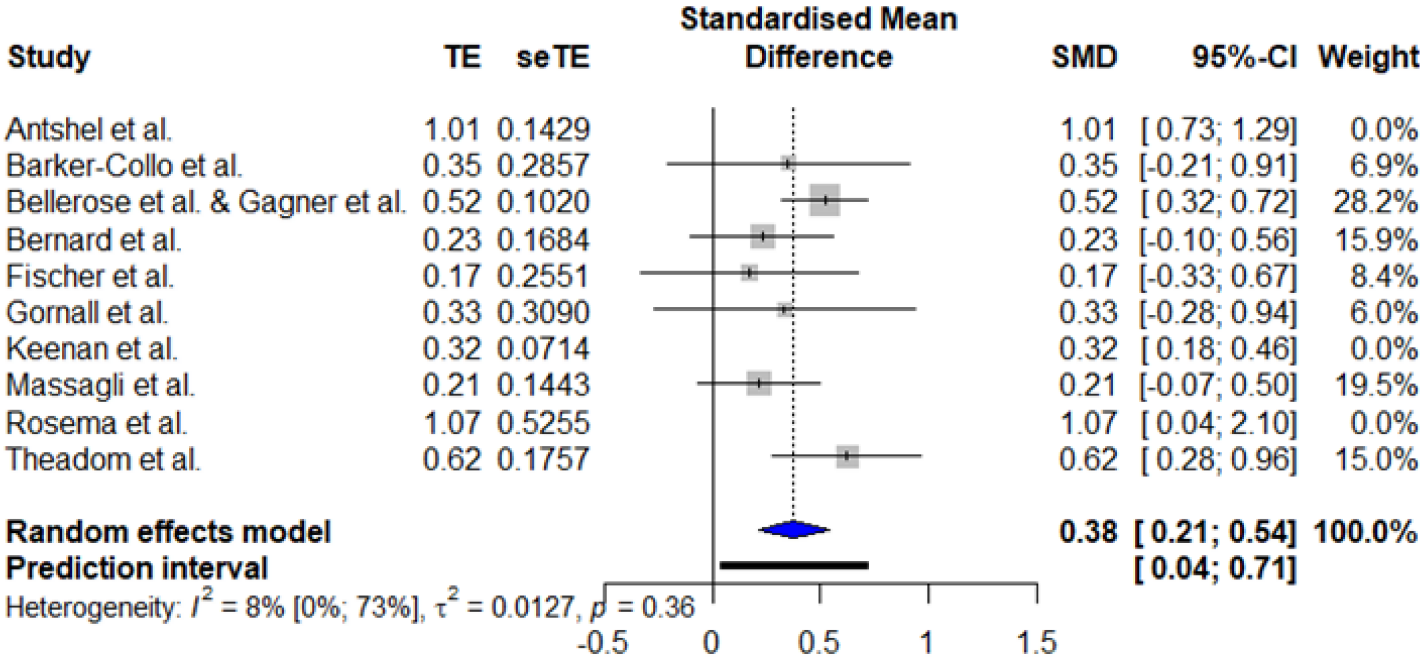
Persisting Internalising Problems (3-12 months)



Chronic Internalising Problems (>12 months)



Persisting Externalising Problems (3-12 months)



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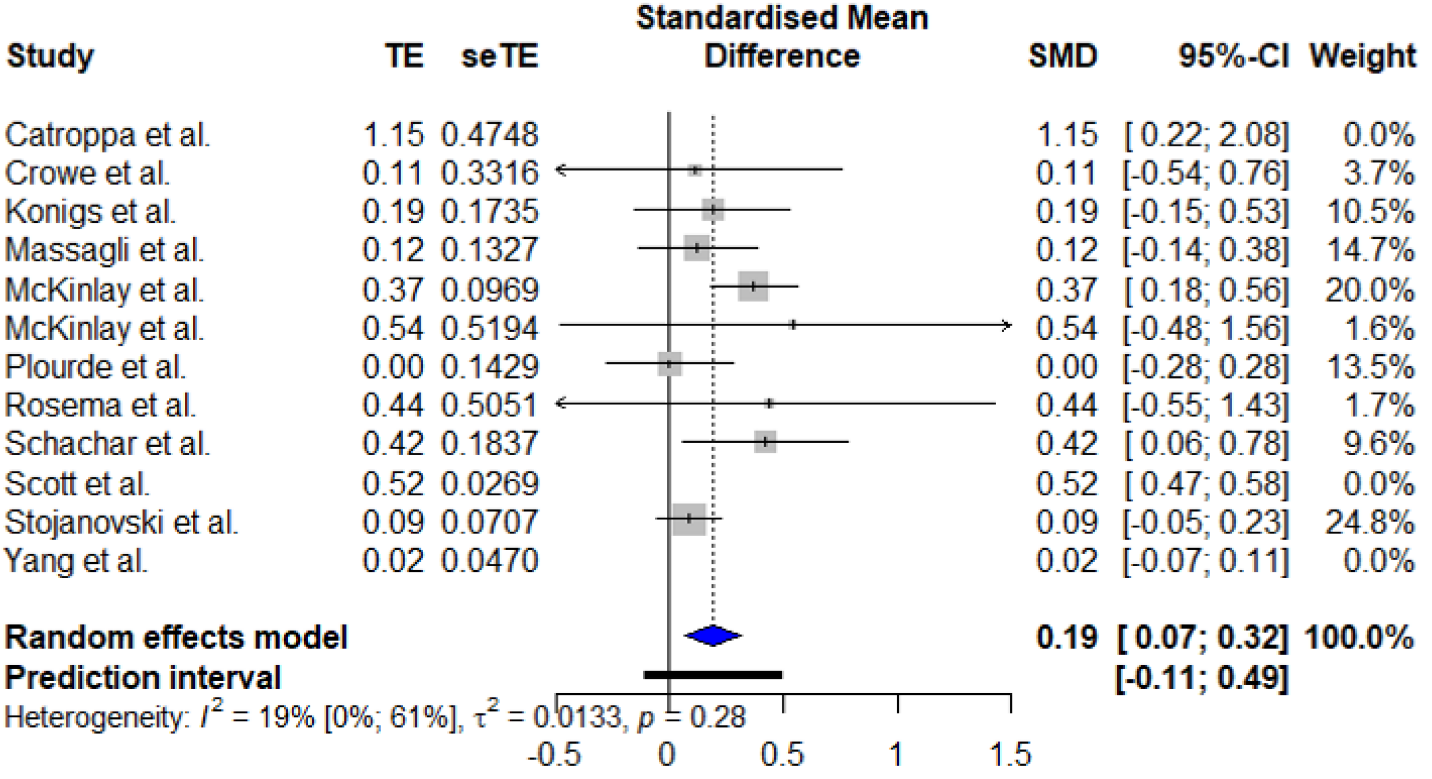
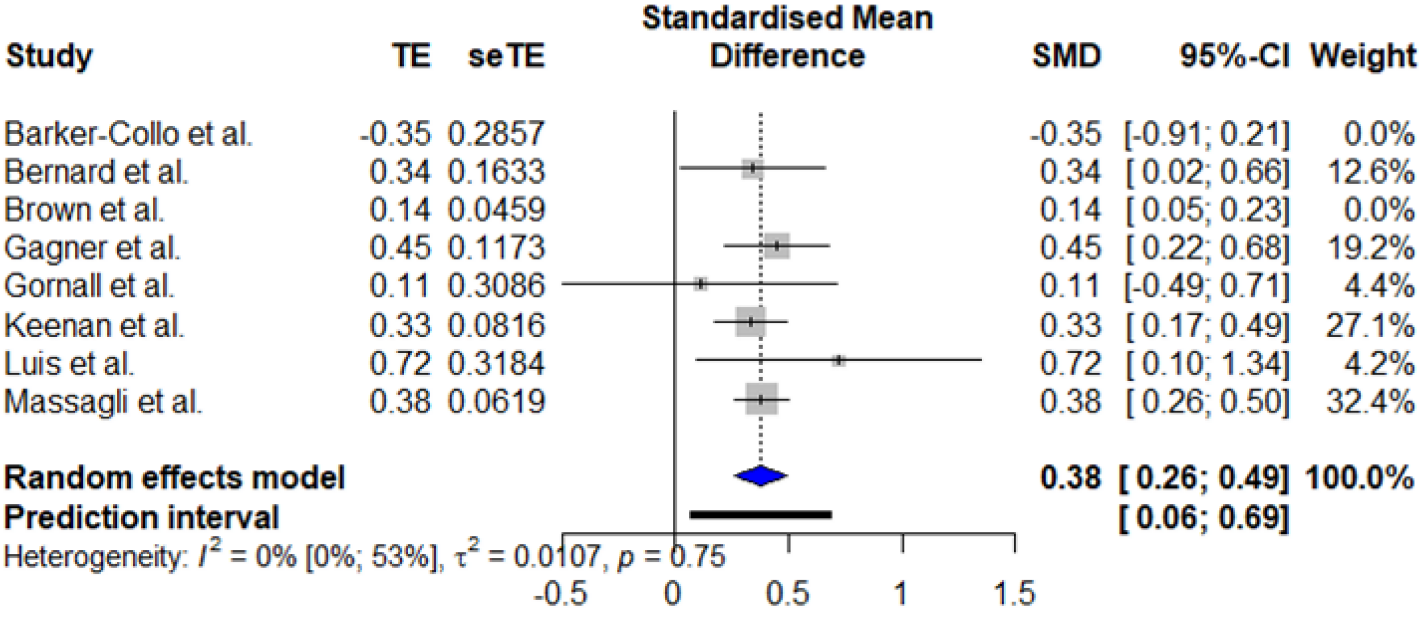
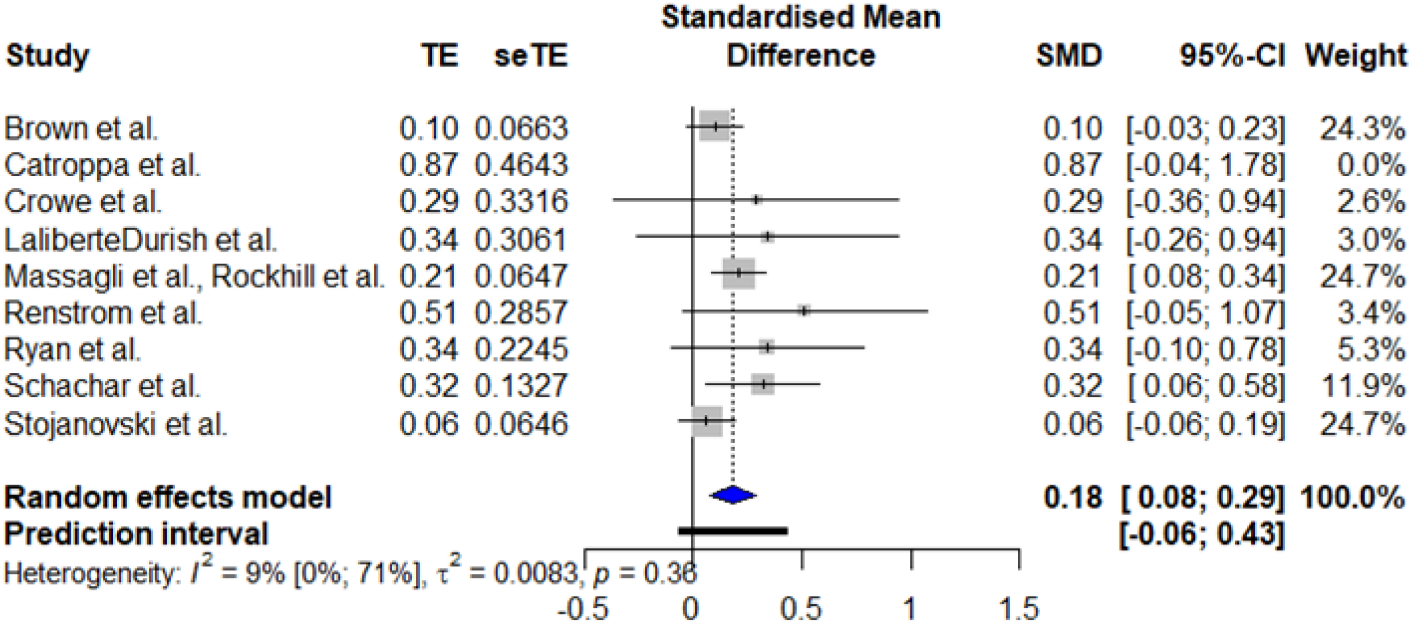


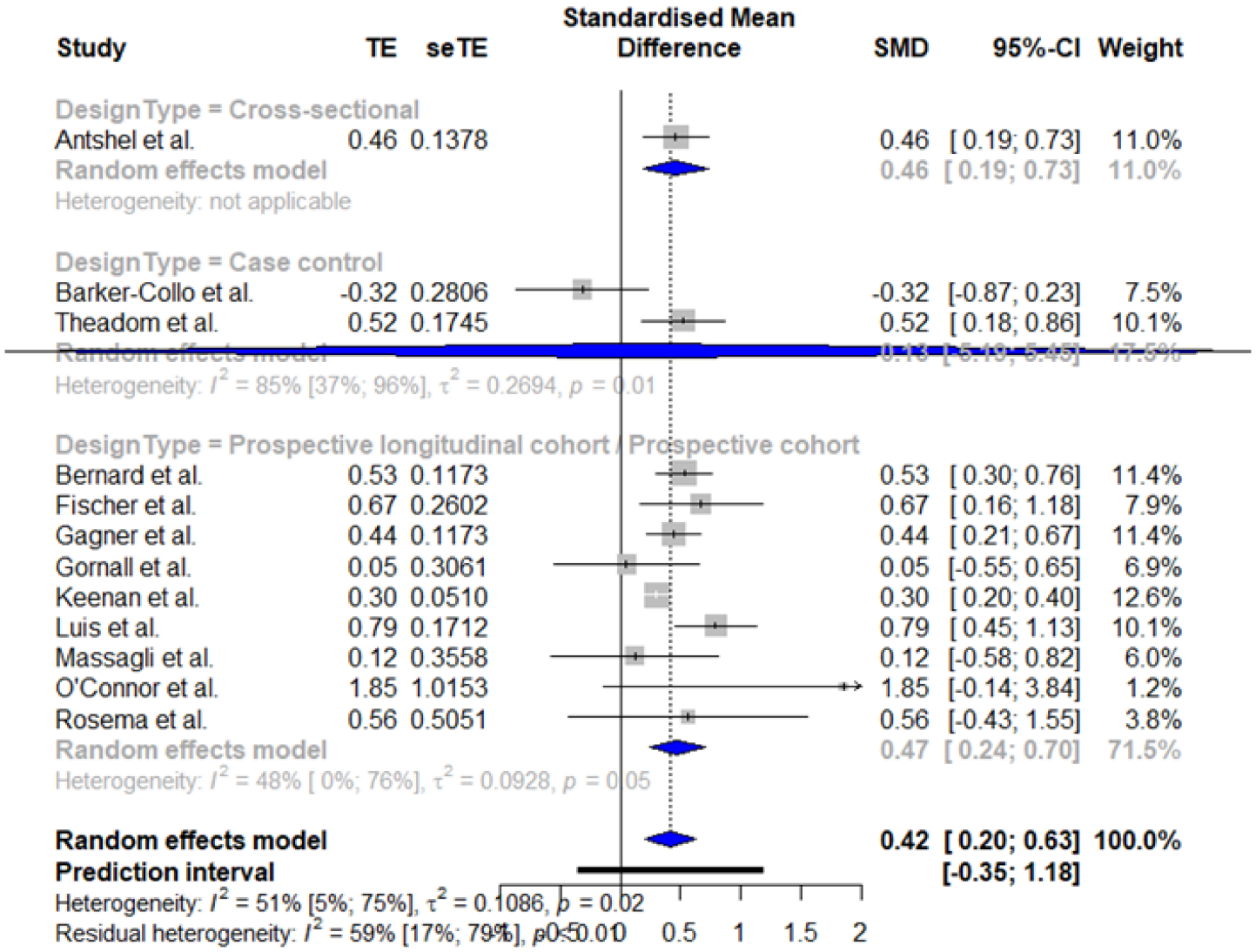
Persisting Total Problems (3-12 months)



Acute Total Problems (>12 months)



Persisting Internalising Problems (3-12 months)



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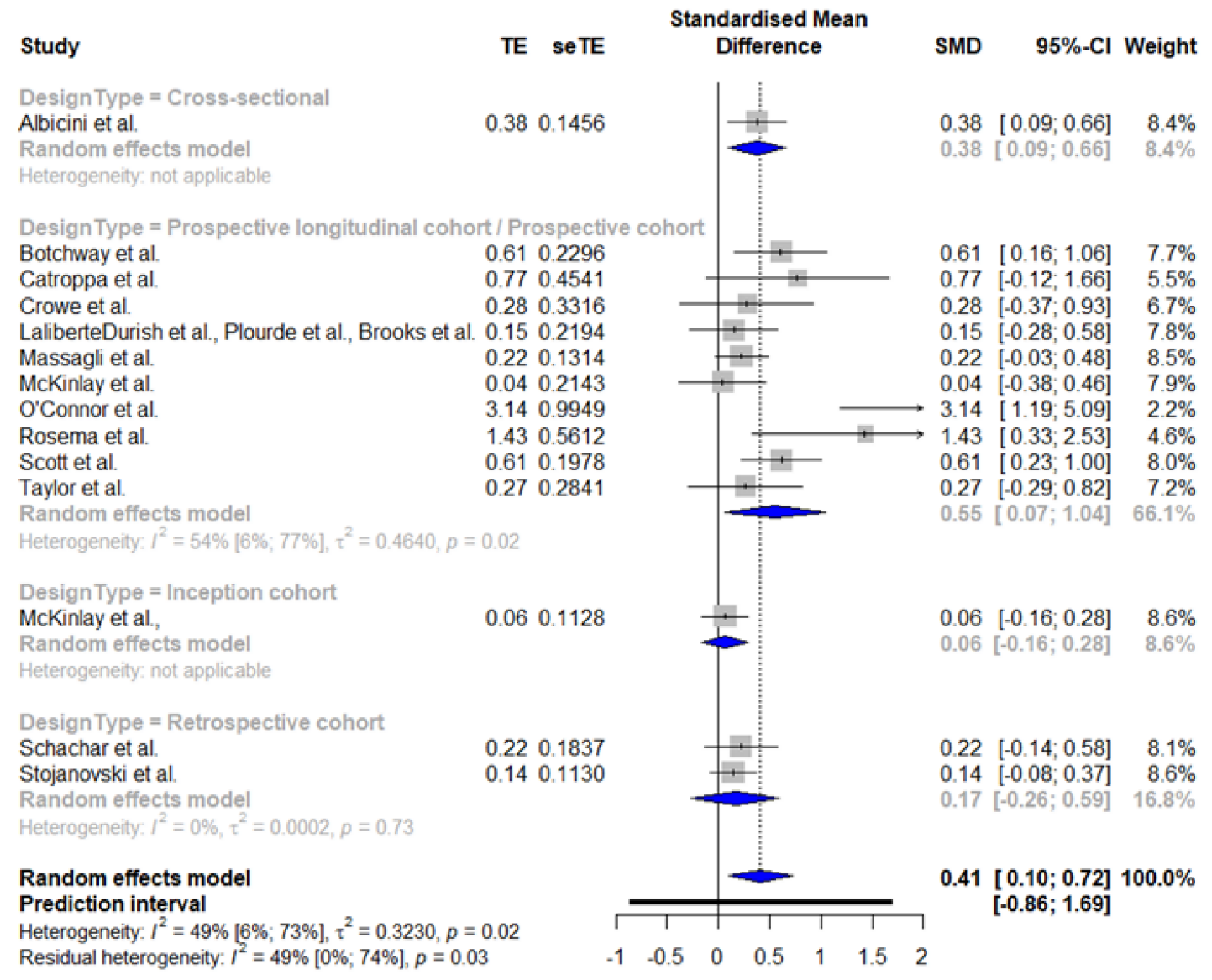

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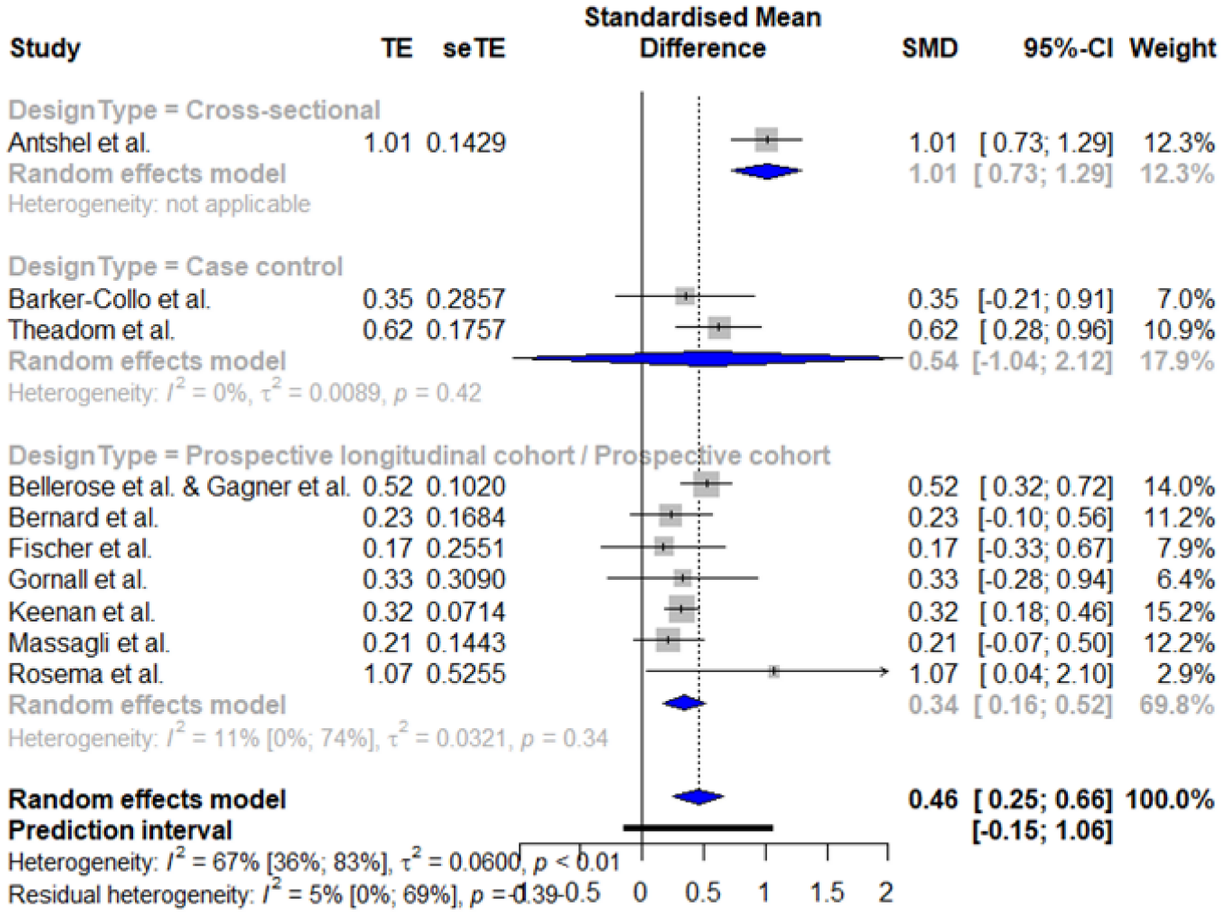

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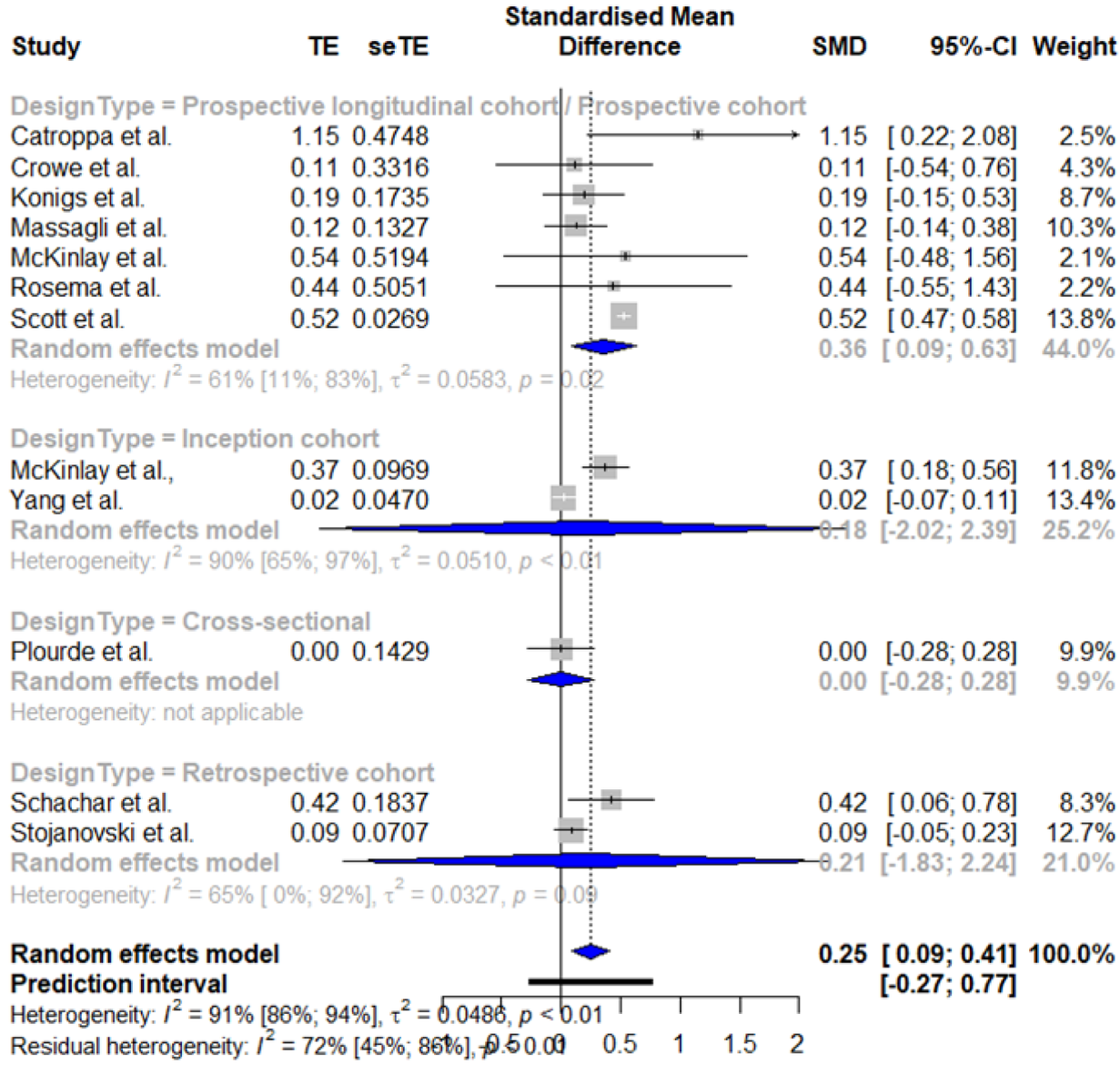

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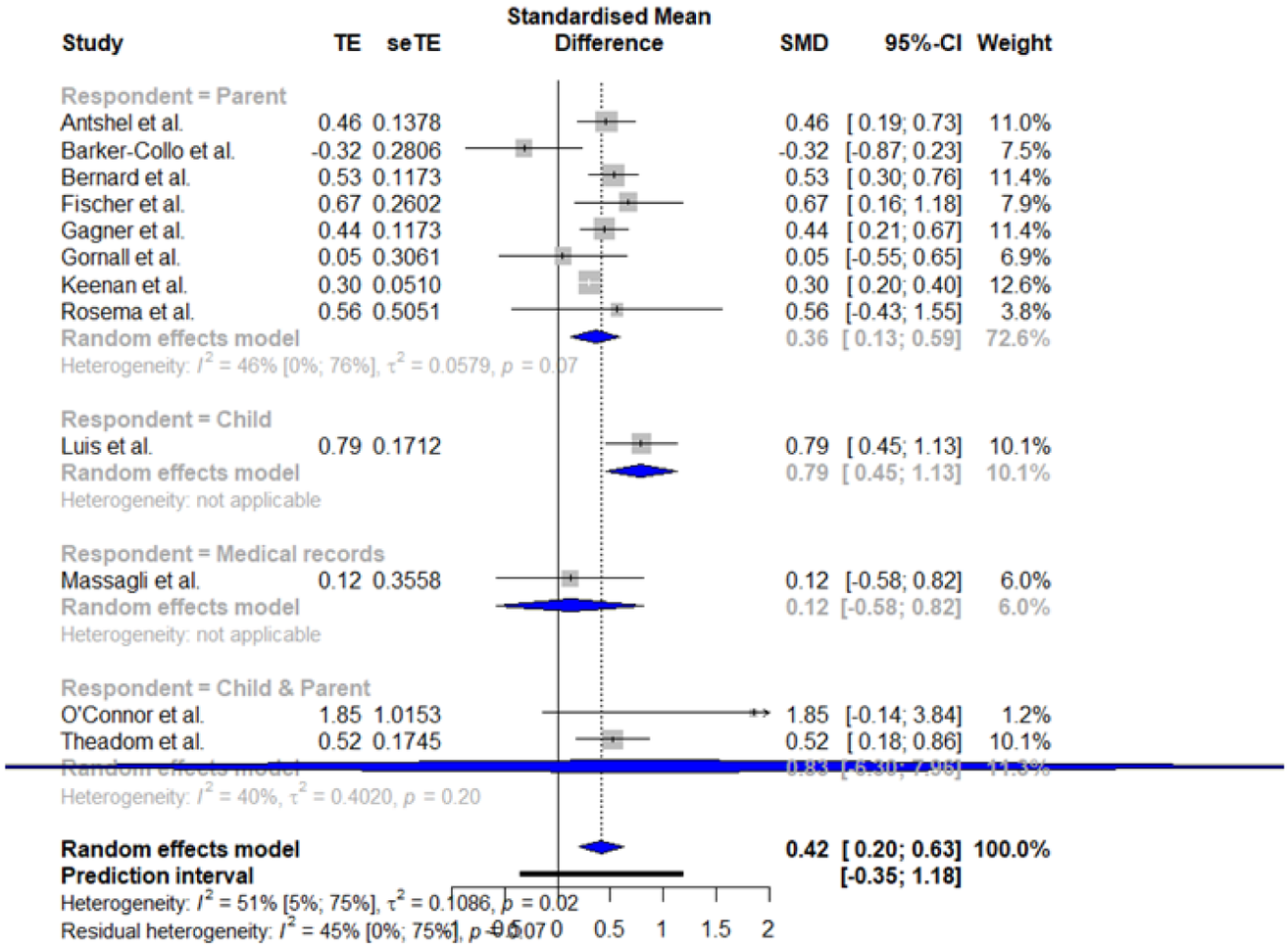
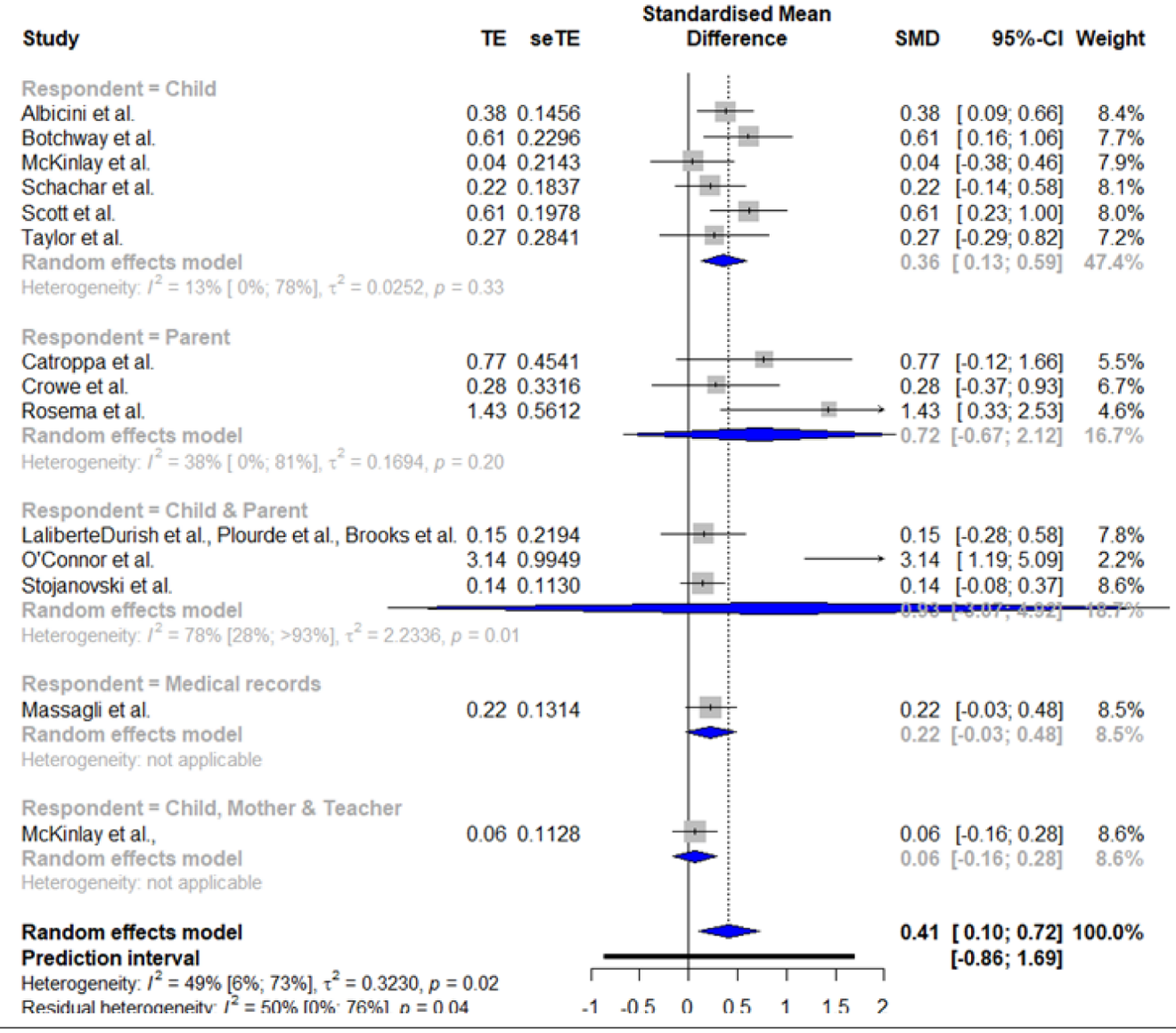


Chronic Internalising Problems (>12 months)



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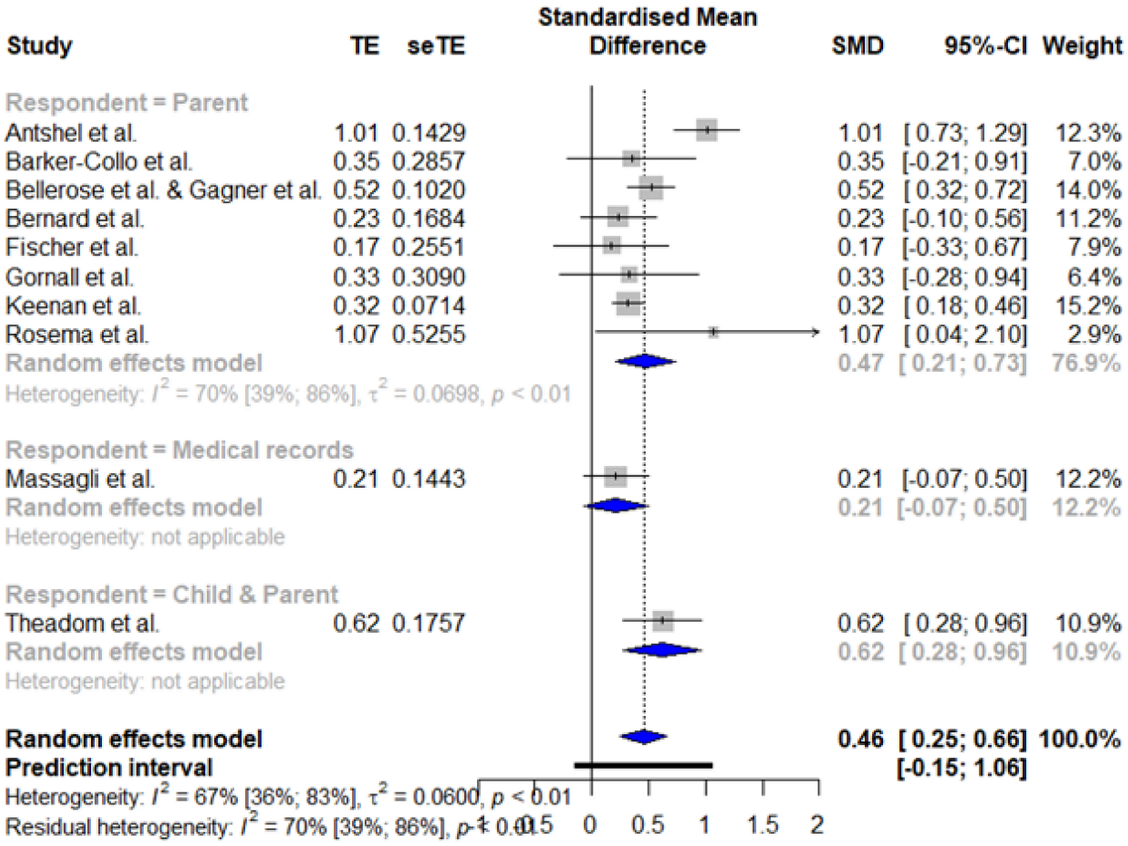

Chronic Externalising Problems (>12 months)