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Developmental trajectories of adaptive functioning following early mild traumatic brain injury

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Running title:

Adaptive functioning development after early mTBI

Adaptive behavior impairments have been reported in children with severe traumatic brain injury (TBI) but are not typically found following mild TBI. It is possible that mild TBI induces subtle changes in adaptive functioning that are not captured in conventional group comparisons. This study aimed to explore time course changes in adaptive functioning following early mild TBI. Parents of 63 children with mild TBI and 53 children with orthopedic injuries aged between 1.5 and 5 years at the time of injury completed the Adaptive Behavior Assessment System-II at three time points: retrospectively to assess pre-injury functioning, then at 6 and 18 months post-injury. Developmental trajectories of adaptive functioning domains (practical, conceptual, and social) reported by parents were modelled using linear mixed-model analyses. Findings suggest that mild TBI may disrupt the expected developmental progression of children's social adaptive behavior, but does not appear to alter practical and conceptual domains.

Key words: traumatic brain injury, preschool children, concussion, social competence, growth curve modeling

Developmental trajectories of adaptive functioning following early mild traumatic brain injury

Childhood traumatic brain injury (TBI) is one of the most frequent causes of interruption to normal development and can result in significant impairments in a range of functional domains including cognition, behavior, and social skills (Beauchamp & Anderson, 2013; Langlois, Rutland-Brown, & Wald, 2006). TBI is particularly prevalent in children younger than 6 years and at such an early age can lead to elevated risk for impairments across the lifespan (Anderson, Catroppa, Morse, Haritou, & Rosenfeld, 2005; McKinlay et al., 2008; Verger et al., 2000). The majority (about 90%) of TBI are of mild severity (Crowe, Babl, Anderson, & Catroppa, 2009; McKinlay et al., 2008); however, even these sometimes result in functional alterations that can interfere with child cognitive and social development, particularly in younger children (Anderson, Catroppa, Morse, Haritou, & Rosenfeld, 2001; Bellerose, Bernier, Beaudoin, Gravel, & Beauchamp, 2017; Gagner, Landry-Roy, Bernier, Gravel, & Beauchamp, 2017; Hessen, Nestvold, & Anderson, 2007; McInnes, Friesen, MacKenzie, Westwood, & Boe, 2017). Functionally, pediatric TBI may have an impact on how children adapt to their environment and perform activities of daily living (i.e., adaptive functioning).

Adaptive functioning refers to a collection of age-appropriate skills in practical (e.g., activities of daily living, self-care, following direction), conceptual (e.g., language, time and number concepts, self-direction), and social (e.g., interpersonal communication, social responsibility and participation in social activities) domains allowing independent and effective functioning in the environment (Harrison & Oakland, 2003; Schalock et al., 2010). Reduced adaptive functioning has been reported in children and adolescents with moderate to severe TBI. Studies indicate a dose-response association between TBI and adaptive functioning, with more

severe injury associated with poorer adaptive functioning (Anderson et al., 2012; Catroppa, Anderson, Morse, Haritou, & Rosenfeld, 2008; Max et al., 1998; Shultz et al., 2016; Taylor et al., 2002; Treble-Barna et al., 2017; Wade, Zhang, Yeates, Stancin, & Taylor, 2016).

Longitudinal studies of children with moderate/severe TBI suggest that impairments in adaptive functioning persist over the long term, and may endure into adulthood (Anderson et al., 2017; Anderson, Brown, Newitt, & Hoile, 2009; Catroppa et al., 2008; Shultz et al., 2016; Taylor et al., 2002; Treble-Barna et al., 2017). Among the three domains of adaptive functioning, social skills appear to be the most profoundly affected after moderate/severe TBI (Anderson et al., 2012; Shultz et al., 2016).

Only one recent study, exploring children's social competence two years after brain injury, reported significantly poorer social adaptive functioning in children with mild TBI (mTBI) compared to typically developing children (Anderson et al., 2017). However, no group differences were identified for the practical and conceptual domains. Other studies that have included children with mTBI in their study population have failed to identify significant changes in adaptive functioning in this sub-group (Anderson et al., 2006, 2012, 2017, 2001; Catroppa et al., 2008; Max et al., 1998). However, mean scores and graphic representation of the data suggest that the level of adaptive functioning of children with mTBI falls somewhere between that of control participants and children with more severe TBI (Anderson et al., 2006; Catroppa et al., 2008; Max et al., 1998), suggesting that their functioning may not be equivalent to that of control participants despite lack of statistically significant differences. Anderson, Catroppa, Haritou, Morse, and Rosenfeld (2005) observed that children with mTBI had stable adaptive ability scores at three measurement time points over 30 months post-injury, which may reflect stagnation in the development of adaptive functioning after mTBI. However, the absence of a

comparison group in their study prevented from confirming this hypothesis. It is also possible that even in the absence of significant group differences at a given time post-injury, changes in adaptive functioning may emerge over time as children are increasingly confronted with more complex environmental demands (Beauchamp & Anderson, 2013). This supposition raises the possibility that mTBI may induce subtle changes in adaptive functioning that are not captured in traditional group comparisons, but that alter its temporal trajectory, stopping or slowing the normal progression of adaptive abilities in children with mTBI. Analytic methods sensitive to longitudinal change, such as linear mixed-model analyses, enable more fine-grained exploration of this hypothesis than the basic group comparisons performed in most studies so far. Indeed, the latter analyses are not well-suited to examine longitudinal changes that occur over time (Gibbons, Hedeker, & DuToit, 2010; Mirman, 2014).

Linear mixed-model analyses, also referred to as multilevel modeling or hierarchical linear modeling, allow explicit modelling of the nested structure of repeated longitudinal data by simultaneously assessing within-individual change and between-individual differences in change over time (Curran, Obeidat, & Losardo, 2010; Hoffman, 2015; Singer & Willett, 2003). Unlike repeated measures analysis of variance or multivariate analysis of variance, linear mixed-model analysis handles challenges associated with longitudinal data, such as partially missing data, unequally spaced time points, non-normally distributed repeated measures, and data collected across a range of ages within any one occasion (Burchinal, Nelson, & Poe, 2006; Curran et al., 2010; Gibbons et al., 2010; Singer & Willett, 2003). Further, linear mixed-models provide higher statistical power than traditional methods applied to the same data (Curran et al., 2010).

The present longitudinal study explored the temporal trajectory of three domains of parent-reported adaptive functioning (practical, conceptual and social) over 18 months following early

mTBI (sustained between the ages of 1.5 and 5 years) using linear mixed-model analysis. We hypothesized that the temporal trajectory of adaptive functioning, particularly in the social domain, would be affected after mTBI in comparison to that of children with orthopedic injuries. This expectation is based on studies reporting reduced adaptive functioning after moderate to severe TBI particularly in the social domain (Anderson et al., 2012; Shultz et al., 2016), and on observations suggesting that the adaptive functioning of children with mTBI may not be equivalent to that of control participants (Anderson et al., 2006, 2017; Catroppa et al., 2008; Max et al., 1998) and may be subject to stagnation in its development (Anderson, Catroppa, Haritou, et al., 2005).

Method

The current data were collected as part of a prospective longitudinal study of cognitive and social outcomes after early TBI (blinded for review). Data from the pre-injury and the 6- and 18-month post-injury time points are reported here. The study was approved by the local human research ethics committee and all families provided written informed consent for participation. As part of the larger study, typically developing control children were also recruited. However, they were not included in the current analyses given that their adaptive functioning was only assessed at two time points and that linear mixed-model analysis requires at least three time points (Hoffman, 2015; Mirman, 2014; Singer & Willett, 2003). Instead, the results of children with TBI were compared to those of a second control group, children with orthopedic injuries (OI), believed to be an optimal comparison group to account for injury related factors (e.g., hospitalization, injury-related pain and stress; Mathias, Dennington, Bowden, & Bigler, 2013; McKinlay et al., 2010; Yeates, 2010).

Participants

Children who sustained mTBI and OI were recruited in an urban tertiary care pediatric Emergency Department between 2011 and 2015. Inclusion criteria for both groups were as follows: (a) age at injury between 18 and 60 months; (b) accidental injury; (c) child and at least one parent fluent in English or French. The following exclusion criteria were applied to all participants: (a) any known congenital, neurological, developmental, psychiatric, or metabolic disorder; (b) less than 36 weeks of gestation; and (c) prior TBI serious enough to warrant a visit to the emergency department.

Diagnostic criteria for the mTBI group were closed head injury (emergency codes screened for potential inclusion were those related to traumatic brain injury, skull fracture, concussion, intracranial bleeding/hemorrhage, and polytrauma) leading to an emergency department consultation with a Glasgow Coma Scale (GCS) between 13 and 15 (Teasdale & Jennett, 1974), and at least one of the following symptoms: persistent vomiting (i.e., more than two times), irritability, loss or alteration of consciousness, amnesia, headaches that worsen over time, drowsiness, dizziness, motor or balance difficulties, blurred vision, hypersensitivity to light and/or seizures. Children with evidence of intracranial lesion on clinical computerized tomography or magnetic resonance imaging (i.e., mild complicated TBI) were recruited, but were not included in the current analyses to present a more homogeneous representation of severity. Diagnostic criteria for the OI group were limb trauma leading to a final diagnosis of fracture, sprain, contusion, laceration, or any other trauma to an extremity. Injury characteristics for the mTBI and OI groups are detailed in Table 1.

[Table 1 should be inserted here]

Procedure

Participants were recruited in one of two ways: *i*) when potentially eligible children visited the ED between 9am and 9pm, a research nurse approached the families directly for participation in the study, *ii*) when potentially eligible children visited the ED outside these hours, the research coordinator contacted the families by phone within 1 week. Families that consented to participate were given a sociodemographic and pre-injury questionnaire booklet at the time of recruitment. Primary caregivers were asked to complete the questionnaire as soon as possible after recruitment (T0, $M = 1.22$ months post-injury, $SD = 0.95$) and to return it by mail. To estimate children's pre-injury functioning, caregivers were asked to complete pre-injury measures based on their child's functioning in the weeks prior to the injury.

Approximately 6 (T1, $M = 6.69$, $SD = 1.06$) and 18 (T2, $M = 18.84$, $SD = 1.24$) months post-injury, primary caregivers completed the same questionnaire booklet as at T0 with regards to their child's functioning in the previous four weeks. At T1 and T2, children completed a comprehensive socio-cognitive assessment battery as part of the larger longitudinal study (data not reported in the present study).

Measures

Sociodemographic characteristics

The primary caregiver completed a form documenting developmental and demographic information including the child's sex, handedness, ethnicity, birth characteristics, as well as developmental and medical history. In addition, parental education was calculated by averaging both parents' highest educational attainment, ranging from 1 (doctoral level) to 8 (less than 7 years of school). When parental highest educational attainment was available for only one parent

no average was computed. If a child lived with one biological parent and a step-parent, the step-parent's information was used in the average.

Case Report Form

Medical information relative to the injury was obtained from medical files from the emergency department consultation for the mTBI group as follows: cause of mTBI, lowest GCS, and neurological signs and symptoms including alteration of consciousness, amnesia, dizziness, drowsiness, headaches, hematoma (forehead or scalp), irritability, loss of consciousness, motor or balance difficulties, persistent vomiting (more than two times), seizures, and visual symptoms (blurred vision, hypersensitivity to light). For children with OI, medical information was documented as follows: cause of OI, diagnosis (fracture, sprain, contusion or laceration) and severity of injury established according to the Abbreviated Injury Scale (Wang & Gennarelli, 2009).

Adaptive functioning

The primary caregiver completed the Adaptive Behavior Assessment System-II (ABAS-II; Harrison & Oakland, 2003) at T0 (retrospective assessment of pre-injury functioning), at 6 (T1) and 18 months post-injury (T2). The ABAS-II is a parent-report questionnaire that provides a comprehensive assessment of everyday adaptive functioning in ten skill areas (communication, community use, functional academics, home living, health and safety, leisure, self-care, self-direction, social, and motor), specifically designed to evaluate patients with neurologic disorders, including TBI (Harrison & Oakland, 2003). The primary caregiver indicates the frequency at which the behavior is demonstrated on a 4-point scale (0 = Is not able, 1 = Never when needed, 2 = Sometimes when needed, 3 = Always when needed). Three standardized domain scores are

derived: Practical (community use + home living + health and safety + self-care), Conceptual (communication + functional academics + self-direction), and Social (leisure + social). A higher score ($M = 100$, $SD = 10$) is indicative of better adaptive skills. This questionnaire has excellent psychometric properties, including adequate internal consistency ($\alpha = .80$ to $.97$) and test–retest reliability ($r = .70$ to $.90$; Harrison & Oakland, 2003). Concurrent validity is supported by correlations (ranging from $.70$ to $.84$) between the ABAS and a variety of other related rating scales (Harrison & Oakland, 2003), notably the Vineland Adaptive Behavior Scale (Sparrow, Balla, & Cicchetti, 1984) and the Behavior Assessment System for Children (Reynolds & Kamphaus, 1992).

Child behavior

At each time point, the primary caregiver completed the Child Behavior Checklist (CBCL; Achenbach & Rescorla, 2001, 2000), a parental report questionnaire assessing child behavior and emotional adjustment rated on a 3-point scale (0 = Not true, 1 = Somewhat or sometimes true, 2 = Very true or often true). Raw scores were used in the present study to prevent reduced variability due to truncated T score transformations (Thurber & Sheehan, 2012). CBCL truncated T score transformations result in the elimination of the lower portion of the score distribution with scores at and below the mean being assigned a T-score of 50 (Achenbach & Rescorla, 2001; Thurber & Sheehan, 2012). Thus, using raw scores in group analyses accounts for the full range of variation (Achenbach & Rescorla, 2001). Higher scores suggest more behavioral or emotional problems. The CBCL has good psychometric properties (Achenbach & Rescorla, 2001).

Family functioning

At each time point, the primary caregiver completed the general functioning scale from the Family Assessment Device (FAD; Epstein, Baldwin, & Bishop, 1983) which assesses overall family functioning. Each of the 12 items is rated on a 4-point scale corresponding to the degree to which the statement describes the family. Higher scores indicate poorer family functioning. This subscale has excellent psychometric properties (Epstein et al., 1983; Miller, Epstein, Bishop, & Keitner, 1985).

Statistical analyses

Demographic and pre-injury characteristics

Group comparisons (independent sample *t*-tests and chi-square tests for continuous and categorical variables respectively) were conducted on demographic variables (child's age, sex and ethnicity, and parental education) and pre-injury child behavior and family functioning to ensure that groups were comparable.

Adaptive functioning developmental trajectories

Linear mixed-model analyses (Mirman, 2014) were used to examine group effects on the trajectory of each domain of adaptive functioning (practical, conceptual, and social) over 18 months post-injury. Analyses were carried out in R version 3.3.2 using the lme4 package.

Three linear models were specified for each domain of adaptive functioning (practical, conceptual, social) and a sequential approach was used to ascertain the best-fitting models (Mirman, 2014): *i*) an unconditional growth model (Model 1) testing the linear fixed effect of time in adaptive functioning domains; *ii*) a conditional model (Model 2) examining the fixed

effect of group (mTBI vs OI) on the initial status (intercept) of adaptive functioning domain (i.e., this model tests for group differences at T0); and *iii*) a conditional model (Model 3) examining the fixed effect of group on the rate of change (i.e., this model tests whether group status predicts the slope of the trajectory). Models included maximal random-effect structures (variance of the individual trajectories around the mean trajectory) that allowed the model to converge (Barr, Levy, Scheepers, & Tily, 2013). Missing data for outcome variables were handled with full information maximum likelihood (FIML) estimation.

The fixed effects of group on initial status and on rate of change in adaptive functioning domains were added individually (models 2 and 3) and their effects on model fit were evaluated using model comparison. Improvements in model fit were evaluated using a likelihood ratio test based on -2 times the change in log-likelihood (-2LL) between two competing models, which is distributed as χ^2 with degrees of freedom equal to the number of parameters added.

Results

Final sample: Demographic and pre-injury characteristics

Information on recruitment and follow-up is detailed in Figure 1. For both groups, there were no differences in terms of age at injury (mTBI: $t(238) = 0.52$; $p = .60$; OI: $t(255) = -0.33$, $p = .74$) and sex (mTBI: $\chi^2(1) = 0.31$, $p = .57$; OI: $\chi^2(1) = 0.00$, $p = .99$) between those who participated in the study and those who refused to participate.

Concerning attrition, 12 mTBI (11%) and 17 OI (17%) dropped out before T0 (families consented but never returned the questionnaires and did not show up for the study), 6 mTBI (5%) and 10 OI (10%) dropped out between T0 and T1, and 15 mTBI (14%) and 7 OI (7%) between T1 and T2. In addition, 13 mTBI (12%) and 12 (12%) OI were excluded *a posteriori* because

they did not satisfy an inclusion criterion and/or presented an exclusion criterion that had not been detected prior to testing (e.g., developmental or psychiatric disorder). For both groups, there was no difference in terms of age at injury (mTBI: $t(107) = -0.24, p = .81$; OI: $t(96) = 0.19, p = .85$) and sex (mTBI: $\chi^2(1) = 0.04, p = .84$; OI: $\chi^2(1) = 0.15, p = .70$) between those who dropped out or were excluded *a posteriori* and those who maintained their participation until T2.

The final sample consisted of 63 mTBI (33 boys, 52%) and 53 OI (25 boys, 47%). Primary caregivers were 86% and 92% mothers in mTBI and OI groups respectively ($\chi^2(1) = 1.31, p = .25$). As detailed in Table 2, the two groups did not differ on demographic variables (child age at injury and at each assessment, sex, ethnicity, or parents' education level), nor on pre-injury measures of child behavior (CBCL) and family functioning (FAD).

[Figure 1 should be inserted here]

[Table 2 should be inserted here]

Main analyses: Developmental trajectories of adaptive functioning

Eight mTBI and two OI participants had missing data for one time point. Three mTBI and one OI missed two time points. As linear mixed-model analysis handles partially missing data in the outcome variable with FIML estimation, these participants were included in the analyses.

Practical adaptive functioning

For the practical domain, the analyses revealed that the unconditional growth model (Model 1) was the best-fitting model (Table 3), thus that there were no statistically significant differences between groups at T0 (Model 2: $\chi^2(1) = 0.11, p = .74$), nor on the rate of change across time (Model 3: $\chi^2(1) = 1.59, p = .21$). The two groups had similar patterns of change

(Table 4; Figure 2a) with a linear increase in practical adaptive abilities of approximately 0.18 ($SE = 0.06$) point per month. Pre-injury practical abilities were found to have an average score of 89.84 ($SE = 1.11$). Note that more conservative models including potential covariates that are often found to be associated with children's adaptive functioning (i.e., child sex, ethnicity, age at injury and behavior, parental education and family functioning) yielded similar results (see supplementary).

Conceptual adaptive functioning

For the conceptual domain, the best-fitting model was also the unconditional growth model (Model 1; Table 3). Hence, there was no effect of group at T0 (Model 2: $\chi^2(1) = 0.28, p = .59$), nor on the rate of change across time (Model 3: $\chi^2(1) = 0.03, p = .85$). The two groups had similar patterns of change (Table 4; Figure 2b) with a linear increase in conceptual adaptive abilities corresponding to approximately 0.07 ($SE = 0.06$) point per month. Pre-injury conceptual abilities were at an average score of 96.66 ($SE = 1.08$). Note that more conservative models including potential covariates provided similar results (see supplementary).

Social adaptive functioning

For the social domain, the best-fitting model was the second conditional model (Model 3; Table 3). There was no effect of group at T0 (Model 2: $\chi^2(1) = 0.16, p = .69$), but a significant effect of group was found on the rate of change across time (Model 3: $\chi^2(1) = 4.12, p = .04$). Social adaptive abilities in the mTBI group showed an essentially flat developmental trajectory, with a linear change of approximately -0.002 ($SE = 0.14$) point per month (Table 4; Figure 2c). In contrast, social adaptive abilities in the OI group increased linearly by approximately 0.28 ($SE = 0.10$) point per month (Table 4; Figure 2c). Pre-injury social abilities were at an average score

of 103.22 ($SE = 2.47$) for the mTBI group, and 101.53 ($SE = 1.80$) for the OI group. More conservative models including potential covariates provided similar results (see supplementary).

[Table 3 should be inserted here]

[Table 4 should be inserted here]

[Figure 2 should be inserted here]

Complementary analyses to explore contributors to social adaptive functioning in the mTBI group

To explore possible predictors of social adaptive functioning over time in the mTBI group, we performed a linear mixed modeling analysis on social ABAS scores in the mTBI group with FAD, CBCL and parental education as predictors. As FAD and CBCL are time-varying predictors, both the between-subject and within-subject information they contain must be represented explicitly in the models (Hoffman, 2015). The between-subject aspect of the CBCL and FAD corresponds to status at T0, whereas the within-subject portion refers to the deviation from the T0 value at each time point. To test the effect of the predictors on social adaptive functioning 18 months post-injury, the intercept was defined at T2 (0 = 18 months). All predictors were centered at a constant to create a meaningful 0 value (Hoffman, 2015). The model revealed that change in CBCL and FAD scores was negatively associated with social adaptive functioning change (Table 5). This result suggests that an increase in child behavior problems and a decrease in family functioning after mTBI may be associated with poorer development of social adaptive functioning in children who sustain early mTBI. The causality of the association between social adaptive functioning, family functioning and child behavior problems cannot be tested, but it is likely to be bi-directional.

[Table 5 should be inserted here]

Discussion

The objective of this longitudinal study was to investigate the temporal trajectory of three domains of adaptive functioning (practical, conceptual and social) reported by parents over 18 months after their child sustained early mTBI (i.e., before age 6). Using linear mixed-model analysis, an analytic method sensitive to longitudinal change, practical and conceptual abilities were found to increase during the recovery period after OI and mTBI. However, while social abilities continued to increase over time after OI, they stayed at pre-injury levels after mTBI. Change in child behavior and family functioning after mTBI was associated with change in social adaptive functioning following early mTBI. All analyses were additionally verified by controlling for potential covariates that are often found to be associated with children's adaptive functioning (i.e., child sex, behavior, ethnicity and age at injury, parental education and family functioning), suggesting that the models are robust. This is the first study to provide evidence that mild TBI may disrupt the expected developmental improvement in children's social abilities.

These results suggest that mild TBI sustained during early childhood may alter the developmental trajectory of social adaptive functioning, but not those of the practical and conceptual domains of adaptive functioning. In children with moderate to severe TBI, reduced adaptive functioning has been reported across all three domains, but social adaptive abilities are the most frequently and profoundly affected (Anderson et al., 2012; Shultz et al., 2016). Together, these findings suggest that children's social adaptive functioning may be affected across the range of injury severities, while changes in the practical and conceptual domains

perhaps are restricted to more severe injuries. Practical adaptive functioning includes personal and instrumental self-care activities such as toileting, dressing, and eating, as well as caring for possessions, and following safety rules (Harrison & Oakland, 2003; Schalock et al., 2010). Severe TBI may affect these abilities to a greater extent than mild injuries because it is more likely to incur motor problems that are disabling in everyday life, for example, as a result of significant brain insult or polytrauma. Conceptual adaptive functioning refers to communication, pre-academic and self-direction skills such as language, number concepts, completing tasks and following instructions (Harrison & Oakland, 2003; Schalock et al., 2010). In content, abilities measured in the conceptual domain are closely related to those reflecting general intelligence (Murray, McKenzie, & Murray, 2014). Thus, it is not surprising that this domain is more clearly affected after severe injuries, which have been shown to alter intellectual functioning, as opposed to mTBI, which does not typically affect general intelligence (Anderson et al., 2001; Anderson, Morse, Catroppa, Haritou, & Rosenfeld, 2004; Max et al., 1998).

Contrasting with the absence of effect in the practical and conceptual domains, the current findings suggest that even mTBI sustained in the first years of life is likely to disrupt social adaptive development. Social adaptive functioning refers to age-appropriate abilities that allow children to interact appropriately and effectively with others and includes participation in play and recreation activities, engaging in social interactions, as well as making and maintaining friendships (Harrison & Oakland, 2003; Schalock et al., 2010). Previous studies using linear mixed-models reported long-term consequences of moderate to severe TBI on the development of social abilities, including social adaptive functioning (Taylor et al., 2002; Yeates et al., 2004), however the present results are the first to identify such an effect after milder injuries. Social competence depends on both individual (i.e., child behavior and social cognitive functioning)

and family environmental factors (i.e., parental responsiveness, adjustment and resources) which may be affected after TBI regardless of severity (Beauchamp & Anderson, 2010; Ryan et al., 2016; Yeates et al., 2007). Consistent with this, the complementary analyses suggest that an increase in child behavior problems and a decrease in family functioning after mTBI may be associated with poorer development of social adaptive functioning following early mTBI. The complexity and multi-determinism of social competence (Beauchamp, 2017) may explain why this domain is vulnerable even to mTBI and why social dysfunction may be present across the range of injury severities. Overall, mTBI may specifically affect the social domain of adaptive functioning because social competence depends on child behavior and family environment which may both be perturbed after mTBI (Gagner et al., 2017; Ganesalingam et al., 2008), whereas practical and conceptual adaptive functioning include abilities less likely to be affected after mild brain injury such as motor function (Forsyth & Kirkham, 2012) and general intelligence (Anderson et al., 2001, 2004; Max et al., 1998).

It is possible that changes in the progression of social adaptive abilities after early mTBI are associated with underlying social cognitive mechanisms. Two previous studies from the current cohort found differences in theory of mind (ToM), the ability to understand the mental states of others (Frith & Frith, 2005), between children with mTBI and control participants, with poorer ToM performance at 6 and 18 months after TBI (blinded for review). A third study from the same cohort reported lower quality of parent-child interaction following early mTBI when compared to non-injured children, reflecting greater relational difficulties that can impact overall social functioning (blinded for review). Together, these studies and the current results suggest that mTBI sustained during early childhood may disrupt social cognition (ToM), social interaction (parent-child interaction), and social adjustment (social adaptive functioning). Given

that social cognitive abilities, such as ToM, are crucial in the establishment of adequate social competence including social adjustment (Beauchamp & Anderson, 2010; Rosema, Crowe, & Anderson, 2012; Yeates et al., 2007), it is plausible that changes in the developmental trajectory of social adaptive functioning observed here operate through more discrete disruptions in underlying cognitive functioning, though this relation has yet to be demonstrated directly.

Improvement in adaptive functioning with age is expected in typical child development (Caravella & Roberts, 2017; Harrison & Oakland, 2003; Oakland & Harrison, 2008). In the present study, children with mTBI had mean adaptive behavior scores within the average range at each time point; however, the slowing in the progression of social adaptive functioning observed throughout the 18-month post-injury period could gradually widen the developmental gap between children who sustain TBI and their peers. Consequently, as children with TBI mature, they may have more difficulties operating within their social environment, which may potentially increase the risk of social isolation and other social difficulties. Further follow-up of the cohort could be useful in determining whether children with TBI bridge the gap in social adaptive functioning with respect to their peers or whether they continue to display differences in this domain.

The current results must be interpreted in the context of some limitations. First, all behavior and adaptive functioning measurements, pre- and post-injury, were based on parent reports and thus reflect parents' perception of their child, which is subject to bias and provides only an indirect index of child outcomes. Although retrospective pre-injury measures provide valuable information of children's pre-injury functioning, there may be some recall bias in parental response to questionnaires. In addition, the TBI event and associated parental distress may influence the perception that parents have of their child's status and functioning (Li & Liu,

2013). To overcome the possible bias associated with parent-rated questionnaires, future studies could consider the inclusion of multiple informants or direct observation of child post-injury functioning and behavior. Second, the variable completion time for the questionnaires at T0 may have introduced some recall bias on pre-injury measures. However, due to the use of linear mixed-model analysis, exact time since injury was explicitly used to model time in the analysis for each child at each time point (T0, T1, T2), which minimized the effects of possible recall bias on the results. Third, though the current data provide a rare opportunity to explore developmental trajectories after preschool TBI over three time points, additional time points would permit estimation of non-linear effects of time. Finally, the current analyses did not include typically developing children as a control group even though they were recruited in the study. However, the OI constitute an appropriate comparison group and is even thought to provide more optimal control over general-injury effects such as fatigue, stress and pain (Mathias et al., 2013; McKinlay et al., 2010; Yeates, 2010). Additionally, previous work on the current cohort indicates that the two control groups may be more similar than expected as they had comparable demographic, developmental, cognitive and family functioning profiles (blinded for review). Of note, as is inevitably the case in longitudinal research, some participants were lost to attrition. However, the current attrition rates (19% of mTBI and 17% of OI dropped out between T0 and T2) were similar to other studies in pediatric TBI (Anderson et al., 2017; Karver et al., 2012; Taylor et al., 2002; Yeates et al., 2004).

Conclusion

In conclusion, using an analytic method sensitive to longitudinal change, this study provides the first evidence that mTBI is associated with altered developmental trajectories of children's social adaptive functions. Although the scores obtained by children with early mTBI remained in

the average range, these young children appear to experience a slowing in the acquisition of social adaptive abilities that may create a widening gap with their typically-developing peers. This article and previous studies conducted with the same cohort provide evidence that mTBI sustained during early childhood may impact the development of child social competence. An intriguing question is whether these group differences have a direct functional impact on recovery after mTBI; to better understand the potential consequences, future research should examine whether a slowing in the acquisition of social adaptive abilities predicts long-term changes in other domains of functioning.

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Table 1: Injury characteristics for the mild traumatic brain injury (mTBI) and orthopedic injury (OI) groups obtained from the medical files from the emergency department consultation.

	mTBI (N = 63)	OI (N = 53)
Cause of trauma [accidental fall], n (%)	59 (94)	32 (60)
Number of neurological signs and injury indicators, <i>M (SD)</i>	3.02 (1.60)	--
Drowsiness, n (%)	36 (57)	--
Extracranial hematoma, n (%)	31 (49)	--
Persistent vomiting, n (%)	30 (48)	--
Headaches, n (%)	21 (33)	--
Alteration of consciousness, n (%)	12 (19)	--
Loss of consciousness, n (%)	11 (17)	--
Motor or balance difficulties, n (%)	10 (16)	--
Dizziness, n (%)	8 (13)	--
Irritability, n (%)	8 (13)	--
Amnesia, n (%)	4 (6)	--
Visual symptoms, n (%)	3 (5)	--
Seizure, n (%)	0 (0)	--
Others, n (%)	16 (29)	--

Note: Others includes other symptoms representative of traumatic brain injury, such as agitation, slowed processing, or excessive fatigue. mTBI = mild traumatic brain injury. OI = orthopedic injury.

Table 2: Demographic, behavior and family functioning characteristics for the mild traumatic brain injury (mTBI) and orthopedic injury (OI) groups.

	mTBI	OI		
	(N = 63)	(N = 53)	<i>t/chi2</i>	<i>p</i>
Sex [male], n (%)	33 (52)	25 (47)	0.31	.58
Parental education, <i>M (SD)</i>	3.12 (1.13)	2.92 (0.92)	1.01	.31
Ethnicity [Caucasian], n (%)	55 (87)	42 (79)	2.64	.10
Age at injury (months), <i>M (SD)</i>	35.84 (11.17)	34.84 (11.46)	0.47	.64
Age at T0 (months), <i>M (SD)</i>	37.39 (11.21)	35.96 (11.34)	0.68	.50
Age at T1 (months), <i>M (SD)</i>	42.37 (11.50)	41.36 (11.32)	0.46	.64
Age at T2 (months), <i>M (SD)</i>	55.22 (11.09)	53.55 (11.97)	0.76	.45
Time between injury and T0 (months), <i>M (SD)</i>	1.31 (1.11)	1.12 (0.72)	0.68	.50
Time between injury and T1 (months), <i>M (SD)</i>	6.62 (1.15)	6.78 (0.95)	-0.80	.43
Time between injury and T2 (months), <i>M (SD)</i>	18.89 (1.23)	18.79 (1.26)	0.44	.66
CBCL at T0 (raw total score), <i>M (SD)</i>	37.51 (17.60)	31.90 (16.53)	1.74	.08
FAD at T0, <i>M (SD)</i>	1.59 (0.42)	1.60 (0.45)	-0.16	.87
Practical adaptive functioning at T0, <i>M (SD)</i>	91.00 (12.06)	89.21 (13.19)	0.74	.46
Practical adaptive functioning at T1, <i>M (SD)</i>	91.30 (11.61)	90.61 (12.91)	0.30	.77
Practical adaptive functioning at T2, <i>M (SD)</i>	92.93 (12.65)	93.88 (12.60)	-0.40	.69
Conceptual adaptive functioning at T0, <i>M (SD)</i>	97.78 (12.34)	96.19 (11.75)	0.70	.49
Conceptual adaptive functioning at T1, <i>M (SD)</i>	97.27 (14.31)	95.59 (11.71)	0.27	.79
Conceptual adaptive functioning at T2, <i>M (SD)</i>	98.72 (12.08)	97.55 (10.01)	0.55	.58
Social adaptive functioning at T0, <i>M (SD)</i>	103.15 (13.93)	102.07 (14.63)	0.40	.70

Social adaptive functioning at T1, <i>M (SD)</i>	103.28 (13.89)	103.33 (13.76)	0.02	.98
Social adaptive functioning at T2, <i>M (SD)</i>	103.24 (14.22)	106.94 (12.24)	-1.45	.15

Note: Parental education was calculated by averaging both parents' highest educational

attainment, ranging from 1 (doctoral level) to 8 (less than 7 years of school). Abbreviations:

CBCL, Child Behavior Checklist. FAD, Family Assessment Device. mTBI, mild traumatic brain injury. OI, orthopedic injury.

Table 3: Results of the linear mixed-model analyses on ABAS components

	Goodness-of-fit	Likelihood ratio test		Best-fitting
	log-likelihood	χ^2	p	model
Practical domain				
Model 1	-1261.9	-	-	X
Model 2	-1261.8	0.11	.74	
Model 3	-1261.0	1.59	.21	
Conceptual domain				
Model 1	-1251.9	-	-	X
Model 2	-1251.8	0.28	.59	
Model 3	-1251.8	0.03	.85	
Social domain				
Model 1	-1304.2	-	-	
Model 2	-1304.2	0.16	.69	
Model 3	-1302.1	4.12	.04	X

Note. Model 1: unconditional growth model testing the linear fixed effect of time. Model 2: conditional model examining the fixed effect of group on initial status (intercept). Model 3: conditional model examining the fixed effect of group on rates of change (slope).

Table 4: Summary of best-fitting models for each adaptive functioning model

	Practical (Model 1)	Conceptual (Model 1)	Social (Model 3)
Fixed Effects			
Intercept [score at T0] Par. est. (<i>SE</i>)	89.84 (1.11)	96.66 (1.08)	mTBI: 103.22 (2.47) OI: 101.53 (1.80)
Time since injury [months] Par. est. (<i>SE</i>)	0.18 (0.06)	0.07 (0.06)	mTBI: -0.002 (0.14) OI: 0.28 (0.10)
Random Effects			
Intercept variance	79.81	80.09	99.65
Residual variance	73.35	65.47	88.22

Note. Model 1: unconditional growth model testing the linear fixed effect of time. Model 2: conditional model examining the fixed effect of group on initial status (intercept). Model 3: conditional model examining the fixed effect of group on rates of change (slope). mTBI = mild traumatic brain injury. OI = orthopedic injury. Par. Est. = parameter estimate.

Table 5: Complementary analyses to explore contributors to social adaptive functioning in the mild traumatic brain injury (mTBI) group

Model effects	Estimate	SE	<i>p</i>
Intercept (T2)	103	1.64	< .0001
Time since injury	0.0004	0.09	.99
Parental education	-1.79	1.67	.28
Parental education * Time since injury	0.05	0.09	.53
FAD at T0	0.08	1.82	.96
FAD at T0* Time since injury	0.01	0.09	.95
CBCL at T0	-3.47	1.85	.06
CBCL at T0* Time since injury	-0.10	0.09	.28
Change in FAD	-1.79	0.92	.05
Change in CBCL	-4.34	1.04	< .0001

Abbreviations: CBCL, Child Behavior Checklist. FAD, Family Assessment Device. mTBI, mild traumatic brain injury. OI, orthopedic injury.

Figure 1: Recruitment and follow-up flowchart for the mTBI and OI participants. ^a The following emergency department diagnoses were considered for participation in the study: mTBI group: traumatic brain injury, head fracture, concussion, intracranial bleeding/hemorrhage, polytrauma; OI group: orthopedic trauma leading to a diagnosis of fracture, sprain, contusion, laceration or any non-specific trauma to an extremity. ^b Potential participants were not eligible because they did not satisfy an inclusion and/or exclusion criterion. ^c Consented refers to those participants whose parents signed a consent form. ^d These participants were excluded *a posteriori* because they did not satisfy an inclusion and/or presented an exclusion criterion that had not been detected prior to testing.

Figure 2: Linear best-fitting model for ABAS practical (A), conceptual (B) and social (C) domains. Mild traumatic brain injury (mTBI) and orthopedic injury (OI) groups had similar pattern of growth for practical and conceptual domains with a linear increase. Social abilities increased over time in the OI group, but not in the mTBI group.