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Le sommeil et les fonctions exécutives après un traumatisme crânio-cérébral léger à l'âge préscolaire

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Le sommeil et les fonctions exécutives après un traumatisme crânio-cérébral léger à l'âge préscolaire

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Résumé

Le traumatisme crânio-cérébral léger (TCCL) est reconnu comme un sérieux problème de santé publique et a fait l'objet de nombreuses études scientifiques étant donné sa prévalence élevée. Les enfants d'âge préscolaire, définis ci-après comme les enfants âgés de cinq ans et moins, constituent un groupe hautement à risque de subir une telle blessure, mais demeurent pourtant sous-représentés dans la littérature. Or, une blessure à un si jeune âge peut être particulièrement redoutable en raison de la vulnérabilité du cerveau immature et du mince registre d'acquis. La présente thèse a pour objectif d'accroître les connaissances scientifiques sur les conséquences du TCCL chez l'enfant d'âge préscolaire. Plus spécifiquement, elle vise à évaluer l'impact d'une telle blessure sur le sommeil et le fonctionnement exécutif.

La thèse est composée de deux articles empiriques. L'objectif du premier article était d'évaluer le sommeil de l'enfant d'âge préscolaire six mois après un TCCL, et d'identifier les facteurs contribuant au sommeil post-TCCL. L'échantillon comprenait 225 enfants âgés entre 18 et 60 mois, répartis en trois groupes : enfants ayant subi un TCCL (n = 85), enfants ayant subi une blessure orthopédique (n = 58) et enfants au développement typique (n = 82). Six mois après la blessure, les parents ont complété l'échelle des problèmes de sommeil du *Child Behavior Checklist*, et un sous-groupe d'enfants a porté un actigraphe pendant cinq jours. Les résultats n'indiquent aucune différence entre les trois groupes d'enfants ni au questionnaire complété par les parents, ni aux paramètres de sommeil mesurés par l'actigraphe, soit la durée et l'efficacité du sommeil nocturne. Toutefois, la présence de difficultés de sommeil pré-morbides et une blessure caractérisée par une altération de la conscience nuisent au sommeil mesuré six mois post-TCCL.

Le deuxième article visait à évaluer le fonctionnement exécutif six mois après un TCCL, et le rôle du sommeil dans le fonctionnement exécutif post-TCCL auprès de la même cohorte d'enfants. Les enfants ayant subi un TCCL (n = 84) et les enfants au développement typique (n = 83) ont été inclus dans les analyses. Les résultats n'indiquent aucune différence de groupe aux épreuves d'inhibition et de flexibilité cognitive administrées six mois après la blessure. Par ailleurs, les enfants ayant subi un TCCL qui présentent plus de problèmes de sommeil ou un sommeil nocturne de plus courte durée ont des performances inférieures aux tâches exécutives comparativement aux enfants au développement typique.

Les résultats de cette thèse permettent une meilleure compréhension du sommeil après un TCCL en bas âge et des facteurs y contribuant. De plus, la thèse démontre l'importance de surveiller le sommeil post-TCCL étant donné que des perturbations de sommeil peuvent avoir des répercussions sur le fonctionnement de l'enfant, notamment sur ses habiletés exécutives.

Mots-clés : traumatisme crânio-cérébral; commotion cérébrale; pédiatrie; enfants; préscolaire; sommeil; actigraphie; cognition; fonctions exécutives.

Abstract

Mild traumatic brain injury (mTBI) is a highly prevalent and serious public health concern. Epidemiological data indicate that preschoolers (i.e., children under 5 years of age) are at especially high risk of sustaining TBI, yet few studies targeted this age group. This is of concern given that the brain is still immature in the early years of life, and children are at the beginning of their development, with few consolidated skills. The overall objective of this thesis is to expand our understanding of the impact of preschool mTBI, specifically on sleep and executive functioning.

The thesis includes two empirical articles. The first article aimed to investigate sleep and its predictors in preschoolers with mTBI. The sample included 225 children, aged 18 to 60 months, divided into three groups: children with mTBI (*n* = 85), children with orthopedic injury (*n* = 58) and typically developing children (*n* = 82). Six months post-injury, parents were asked to fill out the Sleep scale from the Child Behavior Checklist, and children wore an actigraph for five days. No group differences were found in parental ratings of sleep problems or for nighttime sleep duration and sleep efficiency, as measured by actigraphy. However, preexisting sleep disturbances and brain injury resulting in alteration of consciousness were identified as predictors of poorer sleep six months post-injury in the mTBI group.

The aim of the second article was to investigate executive functions six months post-injury in the same cohort of preschoolers, and to determine the role of sleep in the links between mTBI and executive functioning. Children with mTBI (*n* = 84) and typically developing children (*n* = 83) were included in the analyses. There were no significant group differences on measures of inhibition and cognitive flexibility six months post-injury. However, relative to controls, children with mTBI and shorter nighttime sleep duration or increased sleep problems exhibited poorer executive functions.

This thesis allows a better understanding of the factors associated with sleep disturbance after preschool mTBI. In addition, the results highlight the importance of documenting sleep in preschoolers with mTBI, as sleep difficulties place children at risk for later executive dysfunction, which may subsequently impact other spheres of functioning.

Keywords : traumatic brain injury; concussion; pediatric; children; preschoolers; sleep; actigraphy; cognition; executive functions.

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Liste des sigles

ANCOVA: Analysis of covariance

ANOVA: Analysis of variance

AOC: Alteration of consciousness

BO: Blessure orthopédique

CBCL: Child Behavior Checklist

DAS: Dyadic Adjustment Scale

DCCS: Dimensional Change Card Sort

EF: Executive functions

FAD: Family Assessment Device

FE: Fonctions exécutives

GCS: Glasgow Coma Scale

mTBI: Mild traumatic brain injury

OI: Orthopedic injury

PCS: Postconcussive symptom

PCS-I: Postconcussive Symptom Interview

PSI: Parenting Stress Index

SES: Socioeconomic status

TBI: Traumatic brain injury

TCC: Traumatisme crânio-cérébral

TCCL: Traumatisme crânio-cérébral léger

TDC: Typically developing children

Liste des abréviations

c.-à-d. C'est-à-dire

e.g. For example

i.e. That is

p. ex. Par exemple

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CHAPITRE I : Introduction générale

Positionnement du problème

Le traumatisme crânio-cérébral (TCC) représente l'une des causes les plus fréquentes de mortalité et de morbidité chez les enfants (Keenan & Bratton, 2006; Thurman, 2016). D'après une récente revue épidémiologique, on estime que le TCC touche annuellement entre 47 et 280/100 000 enfants à l'échelle mondiale (Dewan, Mummareddy, Wellons, & Bonfield, 2016). Compte tenu de sa prévalence élevée, le TCC est désormais reconnu comme un problème de santé aux proportions épidémiques, et ce, même dans sa forme la plus légère, aussi appelé « commotion cérébrale » ou TCC léger. Le risque de TCC est particulièrement élevé durant la petite enfance (c.-à-d. avant l'âge de cinq ans), ci-après appelé *TCC préscolaire* (Crowe, Babl, Anderson, & Catroppa, 2009; McKinlay et al., 2008). Or, le jeune cerveau est particulièrement vulnérable aux effets d'un telle blessure. La survenue d'un TCC préscolaire peut entraîner des conséquences délétères sur le fonctionnement diurne de l'enfant, que ce soit au niveau cognitif, comportemental ou socio-émotionnel (Anderson, Catroppa, Morse, Haritou, & Rosenfeld, 2005; Bellerose, Bernier, Beaudoin, Gravel, & Beauchamp, 2017; Gagner, Landry-Roy, Bernier, Gravel, & Beauchamp, 2017). En revanche, l'impact d'un TCC préscolaire sur le fonctionnement nocturne est moins bien connu. Pourtant, la revue systématique de la littérature présentée en annexe de cette thèse indique que les perturbations de sommeil sont fréquentes chez les enfants d'âge scolaire et les adolescents après un TCC, même léger (Gagner, Landry-Roy, Laine, & Beauchamp, 2015).

La sous-représentation des enfants d'âge préscolaire dans la littérature est préoccupante étant donné qu'une quantité suffisante de sommeil de bonne qualité est nécessaire pour un développement sain (El-Sheikh & Sadeh, 2015). Le sommeil est particulièrement important pour le fonctionnement cognitif, notamment pour les fonctions exécutives (Bernier, Beauchamp, Bouvette-Turcot, Carlson, & Carrier, 2013; Bernier, Carlson, Bordeleau, & Carrier, 2010). Or, il est bien connu que le TCC lui-même peut occasionner des difficultés exécutives (Levin & Hanten, 2005). Comme le sommeil joue un rôle crucial pour les fonctions exécutives et que ces fonctions sont vulnérables aux blessures cérébrales (Anderson & Ylvisaker, 2009), l'émergence de problèmes de sommeil pourrait compromettre davantage le fonctionnement exécutif post-TCC du jeune enfant.

Ainsi, la présente thèse avait pour objectif d'examiner le sommeil et le fonctionnement exécutif des enfants d'âge préscolaire ayant subi un TCC léger, soit la forme la plus fréquente de TCC (Dewan et al., 2016). Elle visait également à étudier le rôle du sommeil dans le fonctionnement exécutif post-blessure. Dans cette introduction, un aperçu des caractéristiques pathophysiologiques et épidémiologiques du TCC pédiatrique sera d'abord présenté, en portant une attention particulière au TCC préscolaire. Par la suite, les notions de base et des études empiriques sur le sommeil des enfants au développement typique et celui des enfants ayant subi un TCC seront présentées. Puis, le développement des fonctions exécutives et leur vulnérabilité aux TCC seront abordés. Enfin, la relation entre le sommeil et les fonctions exécutives sera discutée. Cette introduction se conclura par la présentation des objectifs et hypothèses de la thèse.

Traumatisme crânio-cérébral

Définition et pathophysiologie. Le TCC est défini comme une perturbation du fonctionnement normal du cerveau suite à une secousse, un impact ou un choc à la tête (Faul, Xu, Wald, & Coronado, 2010). Un TCC peut être causé par une blessure ouverte à la tête, lors de laquelle un objet pénétrant atteint l'os du crâne et les méninges. Or, la majorité des TCC n'impliquent pas d'objet pénétrant, et sont ainsi qualifiés de blessures fermées. Lors d'un TCC, le cerveau est soumis à des forces cinétiques d'accélération, de décélération et de rotation, entraînant un contact avec les parois de la boîte crânienne (Société de l'assurance automobile du Québec, 2016). Ces mouvements peuvent créer des lésions dans le tissu cérébral. Les lésions primaires (p. ex. fractures du crâne, contusions, lésions axonales diffuses) sont directement causées par l'impact à la tête, alors que les lésions secondaires (p. ex. œdème cérébral, complications vasculaires) se développent graduellement après la blessure (Amacher, 1988; Anderson, Catroppa, Beauchamp, & Yeates, 2016). Enfin, des perturbations neurochimiques et neurométaboliques (p. ex. diminution du débit sanguin cérébral, altérations dans le métabolisme du glucose) peuvent s'ajouter aux insultes primaires et secondaires (Prins, Greco, Alexander, & Giza, 2013).

Sévérité. On classifie généralement le TCC selon trois niveaux de sévérité ; léger, modéré et sévère. Il n'existe pas de critères universels pour graduer la sévérité du TCC, mais l'échelle de coma de Glasgow (Teasdale & Jennett, 1974) est la mesure la plus couramment utilisée (Malec et al., 2007; Teasdale et al., 2014). Celle-ci permet de décrire l'état de conscience et le statut neurologique, en tenant compte de l'ouverture des yeux (échelle de 4 points), de la réponse motrice (échelle de 5 points) et de la réponse verbale (échelle de 6 points), pour un maximum de 15 points. Une version pédiatrique de l'échelle de coma de Glasgow a été développée afin de prendre en considération les différences développementales dans les habiletés motrices, verbales et cognitives (James, 1986; Reilly, Simpson, Sprod, & Thomas, 1988). Par exemple, les items verbaux ont été adaptés aux enfants dont la production de langage est caractérisée par des sons ou gémissements. Un TCC sévère est défini par un score à l'échelle de coma de Glasgow entre 3 et 8, un TCC modéré par un score entre 9 et 12 et un TCC léger par un score entre 13 et 15.

La présente thèse se concentre sur la forme la plus courante de TCC, c'est-à-dire le TCC léger (TCCL). Les TCCL représentent à eux seuls entre 70 et 90% des diagnostics de TCC (Cassidy et al., 2004; Dewan et al., 2018). On distingue deux types de TCCL ; simple ou complexe. Le TCCL simple implique une blessure à la tête en l'absence de lésion apparente à l'examen d'imagerie cérébrale, alors que le TCCL complexe est associé à la présence d'au moins une lésion cérébrale intracrânienne (Williams, Levin, & Eisenberg, 1990).

Âge. Les données épidémiologiques indiquent que l'incidence du TCC est particulièrement élevée chez les enfants d'âge préscolaire (Crowe et al., 2009; Faul et al., 2010; McKinlay et al., 2008; Thurman, 2016). En effet, les enfants âgés de cinq ans et moins constituent un groupe hautement à risque de subir un TCC, avec un taux annuel de 1.85 pour 100 enfants, comparativement à des taux inférieurs à 1.17 chez les enfants plus âgés (McKinlay et al., 2008). Conformément à ces statistiques, les registres hospitaliers indiquent que la majorité des consultations à l'urgence en lien avec une blessure à la tête concernent les enfants de moins de quatre ans (Faul et al., 2010). En 2013, près de 305 000 visites à l'urgence et 9 000 hospitalisations liées à un TCC ont été dénombrées chez les enfants de moins de quatre ans aux États-Unis (Taylor, Bell, Breiding, & Xu, 2017). Les chutes (64%) et les collisions avec un obstacle (21%) sont les principales causes de TCC chez ces jeunes enfants (Faul et al., 2010).

La combinaison de plusieurs facteurs anatomiques permet d'expliquer la propension élevée des jeunes enfants à subir un TCC (Ommaya, Goldsmith, & Thibault, 2002). D'une part, l'écart relatif entre la taille de la tête par rapport au reste du corps, ainsi que la faiblesse des ligaments cervicaux et des muscles du cou, limitent le contrôle des mouvements de la tête pour atténuer les forces mécaniques (Huelke, 1998; Noppens & Brambrink, 2004). D'autre part, leur cerveau est moins bien protégé contre les chocs étant donné que le liquide céphalorachidien est moins abondant, que les os crâniens sont plus minces et que les tissus neuronaux sont moins myélinisés (Noppens & Brambrink, 2004; Sookplung & Vavilala, 2009).

Au-delà des facteurs anatomiques, plusieurs considérations développementales rendent le jeune cerveau particulièrement vulnérable aux effets d'un TCC. Selon la théorie de la vulnérabilité, l'acquisition de plusieurs habiletés fondamentales repose sur l'intégrité de certaines structures du cerveau, à des stades développementaux clés (Anderson et al., 2005). Ainsi, une blessure précoce peut compromettre les habiletés émergentes au moment de la blessure, ainsi que les habiletés subséquentes qui reposent sur celles-ci. Les difficultés consécutives à un TCC en bas âge seraient donc cumulatives puisque le jeune enfant a un mince répertoire d'acquis et de connaissances (Anderson, Catroppa, Morse, Haritou, & Rosenfeld, 2000). Cette théorie de la vulnérabilité s'oppose au principe de la plasticité cérébrale. Selon cette conception traditionnelle, une blessure durant l'enfance serait moins redoutable qu'à l'âge adulte, car le jeune cerveau est capable de s'adapter et de se réorganiser. Cette théorie met de l'avant la malléabilité des structures et fonctions du cerveau, où les tissus épargnés peuvent assumer les fonctions des tissus lésés dans le cas d'une atteinte cérébrale (Anderson, Morse, Catroppa, Haritou, & Rosenfeld, 2004). La théorie de la plasticité est souvent associée aux travaux de Margaret Kennard, et est d'ailleurs appelé le « principe de Kennard » par certains auteurs. Dans une série d'études sur les primates dans les années 1930, Kennard avait remarqué que les jeunes primates cérébro-lésés récupéraient mieux que les adultes. Toutefois, elle constatait déjà à l'époque que la récupération cérébrale était complexe et multifactorielle, et que la meilleure récupération chez les jeunes n'était pas un principe universel (Kennard, 1936). Or, une interprétation simplifiée de ses résultats persiste à ce jour (Dennis, 2010). La réalité est beaucoup plus complexe qu'une simple relation linéaire négative entre l'âge au moment de la lésion et la récupération. Le rôle de l'âge dans la récupération serait plutôt modulé par plusieurs facteurs (p.ex. fonction à l'étude).

Conséquences. L'étendue des conséquences suit généralement une relation dite « dose-réponse » avec le niveau de sévérité du TCC. Ainsi, les TCC modéré et sévère sont généralement associés à des atteintes plus importantes, mais le TCC léger (TCCL) peut aussi entraîner un large éventail de conséquences.

Peu après la blessure, le TCCL peut s'accompagner d'une constellation de symptômes de nature variée, appelés symptômes post-commotionnels. Ceux-ci peuvent se présenter sous forme de symptômes cognitifs (p. ex. ralentissement de la pensée, difficultés attentionnelles ou exécutives), physiques (p. ex. maux de tête, nausées, fatigue, difficultés de sommeil) ou psychologiques (p. ex. irritabilité, apathie, anxiété). La présentation et le rétablissement sont variables d'un enfant à l'autre. Dans la majorité des cas, ces symptômes sont transitoires et se résorbent au fil des jours ou semaines qui suivent l'accident. Toutefois, entre 10 et 30% des enfants continuent de présenter des symptômes post-commotionnels trois mois après un TCCL, lesquels peuvent persister dans le temps (Babcock et al., 2013; Barlow, Crawford, Brooks, Turley, & Mikrogianakis, 2015; Barlow et al., 2010).

Les symptômes persistants peuvent entraîner des conséquences dans plusieurs sphères du fonctionnement de l'enfant. D'abord, des difficultés comportementales incluant à la fois des problèmes internalisés (p. ex. retrait, anxiété, dépression) et des problèmes externalisés (p. ex. impulsivité, agressivité) sont fréquemment rapportées après un TCCL (Gagner et al., 2017; McKinlay, Grace, Horwood, Fergusson, & MacFarlane, 2010; Taylor et al., 2015). Le jeune enfant peut aussi présenter des altérations sur le plan des habiletés sociales et sociocognitives, qui se traduisent notamment par de moins bonnes capacités à communiquer et à interagir de manière socialement adaptée (Bellerose, Bernier, Beaudoin, Gravel, & Beauchamp, 2015; Degeilh, Bernier, Gravel, & Beauchamp, 2018; Kaldoja & Kolk, 2012; Lalonde, Bernier, Beaudoin, Gravel, & Beauchamp, 2018; Prigatano & Gupta, 2006). Certaines fonctions cognitives semblent également plus vulnérables aux impacts à long terme d'un TCCL (Babikian et al., 2011; Catale, Marique, Closset, & Meulemans, 2009; Crowe, Catroppa, Babl, & Anderson, 2013). Divers domaines cognitifs peuvent être atteints incluant l'attention, la mémoire ou les fonctions exécutives (se référer à la section « Fonctionnement exécutif post-TCC » à la page 22). Enfin, des perturbations de sommeil sont documentées après un TCCL (Blinman, Houseknecht, Snyder, Wiebe, & Nance, 2009; Pillar et al., 2003; Tham, Fales, & Palermo, 2015; Theadom et al., 2016) et seront abordées ci-après (se référer à la section « Sommeil post-TCC » à la page 15).

Il apparait important de considérer l'impact d'un TCC sur l'enfant blessé, mais aussi sur les parents qui s'occupent quotidiennement de l'enfant. En effet, les parents jouent un rôle important dans la gestion post-TCC et leur réaction émotionnelle est susceptible d'influencer le rétablissement de leur enfant. Suite à la blessure, les parents rapportent souvent de la culpabilité, un sentiment de fardeau, du stress en lien avec leur rôle de parent et de la détresse psychologique (Brown, Whittingham, Boyd, & Sofronoff, 2013; Clark, Stedmon, & Margison, 2008; Stancin, Wade, Walz, Yeates, & Taylor, 2008; Taylor et al., 2001). De telles difficultés sont généralement plus marquées après un TCC modéré ou sévère, mais sont aussi documentées après un TCCL (Ganesalingam et al., 2008; Hawley, Ward, Magnay, & Long, 2003). Le vécu des parents est certainement modulé par les caractéristiques de la blessure elle-même (p.ex. niveau de sévérité, nature et étendue des conséquences), mais le contexte de l'accident est aussi non-négligeable. En effet, un parent qui est témoin de l'accident (p. ex. un parent voit son enfant chuter dans les escaliers) ou qui est impliqué lors de l'accident (p. ex. un accident de voiture pendant que le parent conduit) pourrait ressentir davantage de culpabilité et détresse (Beauchamp, Séguin, Gagner, Lalonde, & Bernier, 2020). Enfin, soulignons qu'une influence réciproque entre le fonctionnement de l'enfant blessé et de sa famille est supporté par la littérature (Taylor et al., 2001).

Sommeil

Sommeil normatif et perturbations de sommeil. Le sommeil est un état physiologique complexe qui se distingue de l'éveil par plusieurs changements physiologiques, dont la respiration, la température corporelle, la posture, le rythme cardiaque, le niveau de vigilance et l'activité cérébrale (Chokroverty, 2017). Le déclenchement du sommeil est dicté par les processus homéostatique et circadien. Le processus homéostatique représente la propension au sommeil qui augmente au fur et à mesure que la période de veille se prolonge, alors que le système circadien est responsable de l'aspect rythmique du cycle éveil-sommeil, indépendamment des périodes de veille et sommeil (Borbély, Daan, Wirz-Justice, & Deboer, 2016; Pace-Schott & Hobson, 2002). Une fois le sommeil engagé, on distingue deux phases de sommeil, soit le sommeil paradoxal, aussi connu sous le terme de sommeil REM (*rapid eye movement*), et le sommeil non paradoxal, aussi appelé sommeil NREM. Ceux-ci donnent lieu à des patrons d'activité cérébrale bien distincts qui peuvent être observés sur un électroencéphalogramme. En effet, le sommeil paradoxal produit une activité cérébrale intense et désynchronisée qui s'apparente à l'éveil. Le sommeil non paradoxal est quant à lui caractérisé par des ondes lentes et synchrones. Il peut être subdivisé en trois stades, du stade 1 plutôt léger au stade 3 très profond, aussi appelé sommeil lent. Le sommeil paradoxal et le sommeil non paradoxal alternent de façon cyclique durant la nuit. Au cours d'une nuit typique, le sommeil non paradoxal est plus concentré en début de nuit. Ensuite, le schéma s'inverse et les épisodes de sommeil paradoxal gagnent en durée au fil que la nuit progresse (Bathgate & Edinger, 2019).

Durant les premières années de vie, la structure et les patrons de sommeil se modifient considérablement, conjointement à la maturation du système nerveux. Peu après la naissance, les périodes de sommeil et d'éveil sont courtes et nombreuses au cours d'une même journée.

Progressivement, les périodes de sommeil et d'éveil vont s'allonger, et les périodes d'éveil vont se concentrer le jour, alors que le sommeil va se consolider la nuit. Vers l'âge de six mois, les enfants atteignent généralement la maturité physiologique nécessaire pour dormir au moins six heures d'affilée la nuit, et on parlera alors d'un rythme circadien veille-sommeil consolidé (Gregory & Sadeh, 2016). L'architecture du sommeil va aussi se modifier drastiquement dans les premiers mois de vie. Le sommeil du nourrisson est caractérisé par deux phases uniques qu'on appelle le sommeil calme et le sommeil agité (Jiang, 2019). Ces deux états vont progressivement se différencier, de sorte que le sommeil agité deviendra le sommeil paradoxal, alors que le sommeil calme prendra la forme du sommeil non paradoxal. De plus, le sommeil paradoxal va diminuer progressivement et laisser plus de place au sommeil non paradoxal. En effet, il passe d'environ 50% chez le nouveau-né à 20–25% chez l'enfant de cinq ans, ce qui correspond à la proportion retrouvée à l'âge adulte (Kahn, Dan, Groswasser, Franco, & Sottiaux, 1996; Lopp, Navidi, Achermann, LeBourgeois, & Diniz Behn, 2017). La quantité de sommeil tend également à diminuer au cours de la petite enfance. Alors que les nourrissons dorment environ 14 heures par jour, la durée de sommeil est estimée à 11 heures chez les enfants âgés de cinq ans (Blair et al., 2012; Iglowstein, Jenni, Molinari, & Largo, 2003).

Au cours de leur développement, les jeunes enfants peuvent rencontrer différentes difficultés de sommeil, dont les plus fréquentes sont les éveils nocturnes répétés et les problèmes d'endormissement (Petit & Montplaisir, 2020). Ils peuvent aussi présenter des parasomnies, c.-à-d. des comportements non-désirés qui interfèrent avec le sommeil, comme le somnambulisme, la somniloquie, le bruxisme et les terreurs nocturnes. Ces perturbations de sommeil sont généralement passagères ou de courtes durées. Toutefois, certains enfants sont plus à risque de souffrir de difficultés sur des périodes prolongées ou de développer des problèmes de sommeil chroniques (Stores, 1999). En effet, des perturbations de sommeil sont fréquentes dans plusieurs troubles de santé mentale (p. ex. anxiété, trouble stress post-traumatique) ou troubles neurodéveloppementaux (p. ex. autisme, déficit de l'attention/hyperactivité; Angriman, Caravale, Novelli, Ferri, & Bruni, 2015; Mayes, Calhoun, Bixler, & Vgontzas, 2009). De plus, le sommeil peut être perturbé par des atteintes physiques occasionnant des douleurs ou symptômes durant la nuit (p. ex. arthrite rhumatoïde juvénile, asthme, problèmes gastriques), ou des atteintes neurologiques (p. ex. épilepsie, blessure cérébrale; Bandla & Splaingard, 2004; Lewandowski, Ward, & Palermo, 2011). Si les perturbations de sommeil sont à l'origine d'une détresse marquée ou d'une altération du fonctionnement, un diagnostic de trouble de sommeil peut être donné par un professionnel conformément aux classifications du Manuel diagnostique et statistique des troubles mentaux (DSM-5; American Psychiatric Association, 2013) ou la classification internationale des maladies (CIM). Il demeure difficile de connaître la prévalence des troubles de sommeil car les estimations varient selon le type de population à l'étude, les méthodes de recension et les outils utilisés. À titre indicatif, Meltzer, Johnson, Crosette, Ramos, et Mindell (2010) ont examiné les dossiers médicaux de plus de 150 000 enfants âgés entre 0 et 18 ans et constaté que 3.7% d'entre eux avaient reçu un diagnostic de trouble de sommeil.

Une altération de la quantité ou de la qualité de sommeil peut entraîner des conséquences néfastes dans plusieurs sphères du fonctionnement de l'enfant. D'abord, des perturbations de sommeil sont associées à diverses conditions médicales telles que les maladies infectieuses et l'embonpoint (Chaput et al., 2016; Orzech, Acebo, Seifer, Barker, & Carskadon, 2014). De surcroît, des difficultés de régulation comportementale et émotionnelle sont fréquentes chez les enfants dont le sommeil est interrompu ou insuffisant (Astill, Van der Heijden, Van Ijzendoorn, & Van Someren, 2012; Gregory & Sadeh, 2012). Par ailleurs, des perturbations de sommeil peuvent avoir des effets délétères sur plusieurs fonctions cognitives et habiletés académiques (Dewald, Meijer, Oort, Kerkhof, & Bogels, 2010; Sadeh, 2007). Le tout considéré, le sommeil apparaît essentiel au bon développement et au bien-être de l'enfant.

Mesures du sommeil. Pour évaluer le sommeil de l'enfant et documenter les perturbations de sommeil, plusieurs instruments subjectifs (questionnaires, agenda) et objectifs (polysomnographie, vidéosomnographie, actigraphie) sont disponibles. Parmi les outils subjectifs, les questionnaires complétés par les parents sont couramment utilisés, et plusieurs d'entre eux sont bien validés (Spruyt & Gozal, 2011), comme le *Child's Sleep Habits Questionnaire* (CSHQ; Owens, Spirito, & McGuinn, 2000), l'échelle des problèmes de sommeil du *Child Behavior Checklist* (CBCL; Achenbach & Rescorla, 2001), et le *Brief Infant Sleep Questionnaire* (BISQ; Sadeh, 2004). Ils consistent à demander au parent de répondre, sur des échelles de Likert, à diverses questions portant par exemple sur les habitudes de sommeil, les comportements reliés au sommeil ou les difficultés de sommeil de l'enfant (Sadeh, 2015). Ainsi, les questionnaires offrent la possibilité d'évaluer rapidement plusieurs sphères du sommeil de l'enfant. Les agendas de sommeil permettent quant à eux de documenter le cycle éveil-sommeil de l'enfant. Pendant plusieurs jours consécutifs, le parent doit indiquer les moments précis durant lesquels l'enfant dort. Plusieurs études empiriques supportent la validité des agendas de sommeil pour les variables reliées à l'horaire (p. ex. heure de coucher et de levée). En revanche, leur validité pour les variables reliées à la qualité de sommeil (p. ex. fréquence des éveils nocturnes) est moindre (Gaina, Sekine, Chen, Hamanishi, & Kagamimori, 2004; Iwasaki et al., 2010; Sadeh, 1996; Werner, Molinari, Guyer, & Jenni, 2008). Les informations fournies par les parents sont limitées à la mesure de leur connaissance des comportements de l'enfant. Par exemple, les éveils nocturnes pourront être rapportés par les parents seulement si l'enfant leur a signalé qu'il était éveillé. En somme, les questionnaires et les agendas de sommeil sont des mesures subjectives peu coûteuses et faciles à utiliser, mais elles sont sensibles au biais du répondant (Bélanger, Simard, Bernier, & Carrier, 2014; Werner et al., 2008).

Parmi les instruments de nature objective, la polysomnographie s'avère la mesure de sommeil par excellence (Sadeh, 2015). Elle consiste à enregistrer un ensemble de paramètres physiologiques (p. ex. mouvements respiratoires, activité électrique du cerveau, activité musculaire, mouvement des yeux) pendant le sommeil à l'aide de plusieurs capteurs et électrodes placés sur différentes parties du corps. Ces informations détaillées permettent d'identifier avec précision les stades de sommeil (paradoxal, non paradoxal) et de poser certains diagnostics cliniques (p. ex. apnée du sommeil). Toutefois, la polysomnographie est très onéreuse et nécessite du personnel qualifié pour l'analyse des tracés dérivés. Conséquemment, les enregistrements polysomnographiques sont souvent limités à une ou deux nuits, ce qui ne permet pas de documenter les patrons de sommeil récurrents. La polysomnographie est une méthode plutôt invasive et s'avère difficile à utiliser avec les jeunes enfants, qui peuvent avoir du mal à tolérer les nombreuses électrodes. Sa propre présence peut aussi affecter la qualité et la durée du sommeil. De même, la polysomnographie est souvent réalisée en laboratoire ou dans une clinique spécialisée dans l'évaluation du sommeil, et les résultats obtenus ne sont pas tout à fait représentatifs du sommeil habituel de l'enfant à son domicile (Marcus et al., 2014). D'autres études utilisent plutôt la vidéosomnographie qui consiste à observer le sommeil de l'enfant dans son environnement naturel par le biais d'enregistrements vidéo. Cette approche permet de caractériser le cycle éveil-sommeil et les comportements de l'enfant (p. ex. parasomnies). Cependant, la vidéosomnographie nécessite l'installation d'équipements au domicile et peut interférer avec les habitudes de la famille ainsi que son intimité (Sadeh, 2015).

Au cours des dernières années, l'actigraphie a connu un essor dans la recherche sur le sommeil. Elle est reconnue comme une méthode d'évaluation du sommeil valide et fiable chez les enfants (Meltzer, Walsh, Traylor, & Westin, 2012; Sadeh, 2011; Spruyt, Gozal, Dayyat, Roman, & Molfese, 2011), incluant les enfants d'âge préscolaire (Bélanger, Bernier, Paquet, Simard, & Carrier, 2013; Bélanger et al., 2014; Sitnick, Goodlin-Jones, & Anders, 2008). Les actigraphes sont de petits appareils de la taille d'une montre, munis d'un capteur de mouvement qui enregistre le niveau d'activité motrice en fonction d'époques temporelles (p. ex. minute par minute). Des algorithmes permettent ensuite de transformer l'activité motrice enregistrée par l'actigraphe en périodes de sommeil et d'éveil en fonction d'un seuil d'activité motrice. L'utilisation d'un agenda de sommeil complémentaire, où les parents détaillent les périodes de sommeil et d'éveil, est indispensable pour retirer au préalable les artefacts potentiels (Meltzer, Montgomery-Downs, Insana, & Walsh, 2012; Sadeh & Acebo, 2002). Les moments où l'enfant ne porte pas l'actigraphe (p. ex. bain) doivent être éliminés des analyses pour ne pas être confondus avec des périodes de sommeil. Les périodes de sommeil ayant lieu dans un véhicule ou dans le même lit qu'une autre personne (co-sommeil) doivent également être exclues pour ne pas être considérées erronément comme des périodes d'éveil. Comme elle est peu invasive, l'actigraphie permet de collecter des données sur une période prolongée, de façon continue. Il est recommandé de remettre l'actigraphe pour une période d'au moins cinq jours afin d'obtenir des données fiables et représentatives (Acebo et al., 1999). Toutefois, il n'est pas inhabituel de retrouver dans la littérature des études qui utilisent l'actigraphie sur de plus courtes périodes (p. ex. trois jours) lorsque l'échantillon est composé de jeunes enfants (Bélanger, Bernier, Simard, Desrosiers, & Carrier, 2018; Scher, Hall, Zaidman-Zait, & Weinberg, 2010; Ward, Gay, Anders, Alkon, & Lee, 2007), tout en maintenant une fiabilité satisfaisante (Sadeh, 2015). Lorsque comparée à la polysomnographie, l'actigraphie présente une bonne sensibilité à détecter le sommeil, mais une plus faible spécificité à détecter l'éveil (Bélanger et al., 2013; Meltzer, Walsh, et al., 2012; Meltzer & Westin, 2011; Sadeh & Acebo, 2002; Spruyt et al., 2011). De plus, cette méthode procure une bonne validité écologique puisqu'elle offre la possibilité de recueillir des données dans l'environnement de l'enfant, tout en étant moins coûteuse.

En somme, plusieurs instruments subjectifs et objectifs peuvent être utilisés pour évaluer le sommeil. Bien que les informations recueillies par ces différentes méthodes puissent se chevaucher, chacune fournit des données uniques et précieuses. Ainsi, il est recommandé d'utiliser une approche multi-modale afin de capturer les différentes facettes du sommeil (Sadeh, 2008; Sadeh, 2015). Dans la présente thèse, l'échelle des problèmes de sommeil du *Child Behavior Checklist* et l'actigraphie ont été utilisées en complémentarité afin de recueillir de l'information détaillée sur les habitudes de sommeil et d'obtenir des données objectives au plan qualitatif et quantitatif.

Sommeil post-TCC

Diverses perturbations de sommeil peuvent émerger chez l'enfant ayant subi un TCC à différentes phases de la récupération. Stores et Stores (2013) ont proposé de classifier les perturbations de sommeil qui surviennent après un TCC pédiatrique en trois grandes catégories, soit l'hypersomnolence (somnolence excessive), l'insomnie (difficultés d'endormissement ou de maintien du sommeil) et les parasomnies (comportements non désirés qui interfèrent avec le sommeil). La revue de littérature systématique présentée en annexe de cette thèse révèle que les perturbations les plus fréquemment rapportées après un TCC pédiatrique (entre 0 et 18 ans) sont l'hypersomnolence et l'insomnie, alors que les parasomnies sont beaucoup plus rares (Gagner et al., 2015). Ces résultats sont corroborés par une revue similaire publiée récemment par Botchway, Godfrey, Anderson, Nicholas, et Catroppa (2018). Ces perturbations peuvent se manifester à différentes phases de la récupération.

Durant la phase aiguë, soit les quelques semaines suivant l'accident, des perturbations de sommeil sont fréquemment rapportées parmi la constellation de symptômes post-commotionnels. Certaines études ont démontré que ces perturbations tendent à s'atténuer au fil des semaines comme plusieurs autres symptômes post-commotionnels (Blinman et al., 2009; Hooper et al., 2004; Korinthenberg, Schreck, Weser, & Lehmkuhl, 2004). Toutefois, d'autres études suggèrent que ces perturbations peuvent persister à plus long terme chez certains enfants (Beebe et al., 2007; Kaufman et al., 2001; Shay et al., 2014; Sumpter, Dorris, Kelly, & McMillan, 2013). Des perturbations ont été rapportées jusqu'à deux ans (Beebe et al., 2007), voire même plus de trois ans après le TCC (Kaufman et al., 2001).

Bien que la majorité des études documentent des perturbations de sommeil post-TCC, il est à noter que quelques études (p. ex. Fischer, Hannay, Alfano, Swank, & Ewing-Cobbs, 2018; Milroy, Dorris, & McMillan, 2008) ont plutôt démontré le contraire. Par exemple, dans une étude de Milroy et al. (2008), les enfants (7 à 12 ans) ayant subi un TCCL présentaient un sommeil, tel que mesuré par un actigraphe six mois après l'accident, similaire à celui d'enfants ayant subi une blessure orthopédique (BO), soit une blessure musculo-squelettique qui n'implique pas la tête. De plus, les enfants du groupe TCCL ne rapportaient pas plus de perturbations de sommeil à un questionnaire auto-rapporté que leurs confrères. En revanche, les parents du groupe TCCL rapportaient davantage de perturbations de sommeil chez leur enfant que ceux du groupe contrôle. Pour expliquer cette différence, les auteurs soulèvent l'importance de considérer les attentes des parents post-TCCL. En effet, il est à noter que les parents avaient reçu au moment de consentir une fiche d'information sur l'impact d'un TCCL sur le sommeil, ce qui pourrait, selon les auteurs, avoir influencé leur façon de percevoir leur enfant et remplir le questionnaire. De leur côté, Fischer et al. (2018) ont recruté des enfants âgés entre 8 et 15 ans ayant subi un TCC, des enfants ayant subi une BO et des enfants en bonne santé, et leurs parents ont rempli un questionnaire de sommeil. Les résultats n'indiquaient aucune différence entre les enfants ayant subi un TCC et ceux ayant subi une BO à tous les temps de mesure (6 semaines, 6 mois et 12 mois post-blessure). Toutefois, les enfants blessés (TCC et BO réunis en un seul groupe) avaient tendance à présenter plus de perturbations de sommeil que les enfants en bonne santé, mais cette différence n'était pas statistiquement significative.

Les disparités observées dans la littérature peuvent être attribuables, du moins en partie, à l'hétérogénéité des méthodologies utilisées. D'abord, divers instruments sont utilisés pour évaluer le sommeil. La majorité des études ont recours à des mesures de sommeil subjectives, comme des agendas de sommeil, entrevues ou questionnaires. Or, il y a une grande variabilité dans leur utilisation, de sorte que certains auteurs administrent des questionnaires bien validés, alors que d'autres évaluent le sommeil à l'aide d'une seule question (p. ex. Tham et al., 2012). Des mesures objectives, comme la polysomnographie ou l'actigraphie, ont été incluses dans quelques études (p. ex. Kaufman et al., 2001; Milroy et al., 2008; Sumpter et al., 2013; Tham et al., 2015), mais leur utilisation demeure peu courante. Par ailleurs, le temps écoulé depuis le TCC est variable d'une étude à une autre. Comme le sommeil est évalué à différentes phases de la récupération post-TCC, il s'avère ainsi difficile d'obtenir un consensus sur le profil de sommeil de l'enfant ayant subi un TCC.

Les caractéristiques des échantillons sont également très hétérogènes, notamment en ce qui a trait au niveau de sévérité du TCC. Il est particulièrement difficile de tirer des conclusions claires lorsque tous les niveaux de sévérité (léger, modéré, sévère) sont confondus en un seul groupe

(p. ex. Fischer et al., 2018; Hooper et al., 2004; Sumpter et al., 2013). De plus, l'âge des enfants varie d'un échantillon à un autre. Quelques études ont ciblé des groupes d'âge spécifiques, comme par exemple des adolescents âgés entre 12 et 18 ans (Osorio et al., 2013; Tham et al., 2015), mais plusieurs études couvrent un large spectre d'âge, dépassant fréquemment une dizaine d'années. En plus de cette grande variabilité, on constate que très peu d'études ont ciblé les enfants d'âge préscolaire, et ce, en dépit du fait que certains des développements les plus importants dans les patrons de sommeil se produisent avant l'âge de cinq ans (Acebo et al., 2005) et de la prévalence élevée de TCC durant cette période développementale (Crowe et al., 2009). De surcroît, lorsque de jeunes enfants sont inclus dans l'échantillon, ceux-ci sont souvent regroupés avec des enfants plus âgés et des adolescents (Korinthenberg et al., 2004; Tham et al., 2012), ce qui empêche de tirer des conclusions spécifiques à ce groupe d'âge. À notre connaissance, une seule étude a été menée spécifiquement chez des enfants d'âge préscolaire (Shay et al., 2014). Les parents dont l'enfant avait subi un TCC léger complexe/modéré ou un TCC sévère entre les âges de trois et six ans rapportaient davantage de difficultés de sommeil six mois après la blessure que les parents dont l'enfant avait subi une BO. Les résultats de cette étude sont malheureusement limités par l'utilisation d'une seule méthode d'évaluation subjective du sommeil, c.-à-d. un questionnaire complété par les parents. De plus, les résultats ne s'appliquent pas au TCC dans sa forme légère.

Facteurs contribuant aux perturbations de sommeil post-TCC. Une panoplie de facteurs, souvent en combinaison, peuvent contribuer à l'émergence et au maintien de problèmes de sommeil post-TCC. Ces facteurs sont bien documentés chez l'adulte et ont été répertoriés dans le modèle de Ouellet, Beaulieu-Bonneau, et Morin (2015). Celui-ci décrit une constellation de facteurs pré-blessures, péri-blessures, aigus et post-aigus associés à des difficultés de sommeil.

Premièrement, les facteurs pré-blessures incluent les caractéristiques du patient (p. ex. sexe, gènes, état de santé). De plus, le profil de sommeil avant l'accident (p. ex. horaire de sommeil, durée et qualité de sommeil, fréquence des siestes) est déterminant. Il est bien documenté que la présence de difficultés de sommeil avant l'accident est associée à davantage de difficultés après un TCC (Theadom et al., 2015). *Deuxièmement*, les facteurs péri-blessures font référence aux caractéristiques de la blessure (p. ex. sévérité, forces cinétiques, lieu de l'impact). *Troisièmement*, le sommeil dans la phase aigue peut être perturbé si le patient présente des lésions aux régions impliquées dans le cycle éveil-sommeil (p. ex. formation réticulée, tronc cérébral, noyau suprachiasmatique, hypothalamus) ou des perturbations neurochimiques associées. Les études à ce jour ne permettent pas d'établir un lien étroit entre l'émergence de problèmes de sommeil et des lésions circonscrites. Néanmoins, les études post-mortem auprès d'adultes ayant subi un TCC sévère révèlent des lésions au niveau du noyau tubéromamillaire de l'hypothalamus et du tegmentum mésopontique (Valko et al., 2015; Valko et al., 2016). Par ailleurs, une diminution du niveau d'orexine, un neurotransmetteur qui stimule l'éveil, et de la mélatonine, une hormone qui intervient dans les rythmes circadiens, a été observée chez des adultes ayant subi un TCC modéré ou sévère (Baumann et al., 2009; Baumann et al., 2005; Seifman et al., 2014). Notons que ces dérèglements sont généralement de courte durée et limités à la phase aiguë. De plus, ces dommages sont propres aux blessures les plus sévères, et peu probables après un TCCL. Il apparait donc évident que des facteurs secondaires à la blessure jouent un rôle important dans l'apparition de difficultés de sommeil peu après un TCC. Par exemple, les symptômes post-commotionnels psychologiques (p. ex. anxiété) et physiques (p. ex. maux de tête, nausées, douleurs) peuvent interférer avec le sommeil (Fogelberg, Hoffman, Dikmen, Temkin, & Bell, 2012). De plus, des symptômes de fatigue peuvent augmenter la fréquence des siestes diurnes, et en retour affecter la durée et la qualité du sommeil nocturne (Singh, Morse, Tkachenko, & Kothare, 2016). *Quatrièmement*, plusieurs facteurs individuels et environnementaux post-aigus (p. ex. stresseurs, habitudes de vie) sont susceptibles d'entraîner la chronicisation des problèmes de sommeil à plus long terme. Ainsi, l'ensemble de ces facteurs pré-blessures, péri-blessures, aigus et post-aigus peut expliquer l'hétérogénéité des difficultés de sommeil chez les adultes ayant subi un TCC.

Chez l'enfant, les facteurs associés au sommeil post-TCC sont moins bien documentés (Botchway et al., 2018). Jusqu'à présent, les facteurs identifiés incluent la présence de difficultés de sommeil avant l'accident, un indice de masse corporel élevé, des douleurs ainsi que des problèmes de comportements internalisés ou externalisés (Fischer et al., 2018; Pillar et al., 2003; Tham et al., 2015; Tham et al., 2012). Par ailleurs, les résultats d'une étude suggèrent que les filles seraient plus à risque que les garçons de développer des problèmes de sommeil après un TCC (Tham et al., 2012), mais ce résultat n'a pas été répliqué dans d'autres études (Pillar et al., 2003; Tham et al., 2015). En somme, des études plus approfondies sont nécessaires pour identifier les facteurs contribuant aux difficultés de sommeil chez l'enfant ayant subi un TCC et ainsi intervenir plus rapidement. Le premier article de cette thèse s'est d'ailleurs intéressé à trois familles de facteurs contributifs (c.-à-d. démographiques, pré-blessures et péri-blessures) dans le contexte du TCCL préscolaire.

Fonctions exécutives

Définition et développement. Comme leur nom l'indique, les fonctions exécutives (FE) permettent l'exécution ou la mise en œuvre d'une action. Elles regroupent un éventail de processus impliqués dans toute action adaptative dirigée vers un but particulier (Lezak, 1982). Elles facilitent l'adaptation à des situations nouvelles ou non routinières qui nécessitent l'élaboration, l'exécution et l'évaluation d'un plan plus ou moins complexe. Les FE guident et coordonnent les processus cognitifs, mais également les comportements et réponses socio-émotionnelles au quotidien (Anderson, 2002; Gioia, Isquith, Guy, & Kenworthy, 2000; Roy, Le Gall, Roulin, & Fournet, 2012).

Le développement des FE est intrinsèquement lié à la maturation du cerveau, débutant dès la première année de vie et se poursuivant jusqu'à l'adolescence, voire même au début de l'âge adulte (De Luca & Leventer, 2008). À l'âge préscolaire, on assiste à une maturation cérébrale rapide, incluant notamment une réduction de la densité neuronale, une croissance des dendrites, et une augmentation des volumes de matière grise et blanche (Durston & Casey, 2006; Tsujimoto, 2008). Ces transformations permettent d'établir les réseaux neuronaux à la base du contrôle exécutif, qui implique notamment mais pas exclusivement les régions préfrontales. La période préscolaire est ainsi charnière pour l'acquisition des composantes exécutives élémentaires. Bien qu'il n'y ait pas de véritable consensus scientifique, l'inhibition et la flexibilité cognitive sont communément reconnues comme étant des composantes fondamentales (Anderson, 2008; Clark et al., 2013). Plus précisément, l'inhibition réfère à la capacité de supprimer de façon délibérée une réponse prépondérante, alors que la flexibilité cognitive permet d'alterner entre différentes tâches ou registres mentaux. Comme ces deux fonctions sont en pleine expansion durant la période préscolaire (Carlson, 2005; Garon, Bryson, & Smith, 2008), elles ont été investiguées dans le deuxième article de cette thèse, et mises en relation avec le sommeil post-blessure. Une atteinte des FE fondamentales tôt dans le développement est susceptible d'occasionner des répercussions à long terme. En effet, l'acquisition des composantes élémentaires permet le développement ultérieur des fonctions plus complexes, comme le raisonnement, la résolution de problème et la planification (Collins & Koechlin, 2012; Diamond, 2013; Garon et al., 2008).

Fonctionnement exécutif post-TCC

Les FE sont des fonctions très sophistiquées, mais aussi très vulnérables, notamment aux effets d'un TCC. D'après une revue de littérature réalisée par Levin et Hanten (2005), les FE touchées suite à un TCC pédiatrique sont nombreuses et incluent autant les fonctions à la base du contrôle exécutif, comme l'inhibition et la flexibilité, que les fonctions plus complexes. Ces difficultés exécutives ont été documentées par le biais d'épreuves neuropsychologiques administrées aux enfants (Anderson & Catroppa, 2005; Konrad, Gauggel, Manz, & Schöll, 2000; Levin et al., 2004; Loher, Fatzer, & Roebers, 2014; Mandalis, Kinsella, Ong, & Anderson, 2007; Roncadin, Guger, Archibald, Barnes, & Dennis, 2004), ou des inventaires comportementaux complétés par les parents (Keenan, Clark, Holubkov, Cox, & Ewing-Cobbs, 2018; Mangeot, Armstrong, Colvin, Yeates, & Taylor, 2002; Sesma, Slomine, Ding, & McCarthy, 2008). Les atteintes sont plus fréquentes et plus prononcées suite à une blessure modérée ou sévère. Cependant, les conséquences possibles d'un TCCL sur le fonctionnement exécutif sont plus difficiles à réconcilier, voire parfois contradictoires. De fait, les études qui montrent des difficultés exécutives chez les enfants ayant subi un TCCL (Crowe et al., 2013; Keenan et al., 2018; Loher et al., 2014) contrastent avec celles qui suggèrent un fonctionnement exécutif préservé (Babikian et al., 2011; Beauchamp et al., 2011; Nadebaum, Anderson, & Catroppa, 2007; Taylor et al., 2008).

En ce qui concerne spécifiquement le TCC préscolaire, la littérature est plus restreinte. Pourtant, une blessure durant cette période développementale critique pour l'acquisition des FE pourrait constituer un risque particulièrement prononcé pour l'émergence de difficultés exécutives. À ce jour, des difficultés en termes de contrôle inhibitoire ont été rapportées plus de deux ans après un TCC subi avant l'âge de trois ans (Crowe et al., 2013). En comparaison à des enfants contrôles en bonne santé, les performances des enfants du groupe TCCL et des enfants du groupe TCC modéré-sévère étaient significativement inférieures. Des difficultés de contrôle inhibitoire sont également rapportées plus de cinq ans après un TCC subi entre les âges de deux et sept ans, mais seulement pour les enfants dont la blessure était modérée ou sévère (Catroppa, Anderson, Morse, Haritou, & Rosenfeld, 2007). Par ailleurs, des difficultés à des épreuves de flexibilité ont été documentées après un TCC modéré ou sévère en bas âge (Ewing-Cobbs, Prasad, Landry, Kramer, & DeLeon, 2004; Nadebaum et al., 2007). Enfin, dans un échantillon d'enfants ayant subi un TCC modéré ou sévère entre les âges de trois et sept ans, des déficits en inhibition et en flexibilité sont rapportés 6, 12 et 18 mois post-TCC (Ganesalingam et al., 2011; Gerrard-Morris et al., 2010; Taylor et al., 2008).

Malgré un nombre croissant d'études s'intéressant au fonctionnement exécutif après un TCC préscolaire dans la dernière décennie, les conclusions demeurent difficiles à tirer en raison de nombreux facteurs méthodologiques. D'abord, les TCC accidentels et les TCC infligés sont parfois regroupés (Ewing-Cobbs et al., 2004), bien que ces deux formes soient associées à des pathologies cérébrales et facteurs psychosociaux distincts (Ennis & Henry, 2004; Keenan, Runyan, Marshall, Nocera, & Merten, 2004). Par ailleurs, certaines études n'évaluent les FE que plusieurs années après la blessure (Catroppa et al., 2007; Crowe et al., 2013; Nadebaum et al., 2007), ou n'uniformisent pas le temps écoulé depuis le TCC (Crowe et al., 2013; Ewing-Cobbs et al., 2004). Enfin, plusieurs études se concentrent uniquement sur les TCC modérés-sévères (Ewing-Cobbs et al., 2004; Ganesalingam et al., 2011), et le TCCL demeure négligé dans la littérature.

Sommeil et fonctions exécutives

Les FE sont vulnérables aux atteintes cérébrales, mais également aux perturbations de sommeil. Selon plusieurs auteurs, les régions frontales, qui sont notamment impliquées dans le fonctionnement exécutif, seraient particulièrement sensibles à des perturbations de sommeil (Dahl, 1996; Horne, 1993; Jones & Harrison, 2001; Muzur, Pace-Schott, & Hobson, 2002; Wu et al., 2006). À ce jour, les mécanismes neuronaux et neurochimiques sous-jacents demeurent incompris. Il a cependant été proposé que les régions frontales bénéficieraient particulièrement du rôle récupérateur du sommeil étant donné leur niveau d'activité élevé durant la journée pour soutenir plusieurs processus cognitifs (Turnbull, Reid, & Morton, 2013).

Plusieurs études se sont intéressées à l'association entre les FE et le sommeil de l'enfant. Chez les enfants au développement typique, un sommeil insuffisant ou de piètre qualité est associé à des difficultés exécutives (Holley et al., 2014; Sadeh, Gruber, & Raviv, 2002; Steenari et al., 2003). Par exemple, une étude de Sadeh et al. (2002) révèle que les enfants âgés de sept à neuf ans dont le sommeil est fragmenté performent moins bien aux tâches exigeant un contrôle exécutif. En revanche, leur performance est intacte aux tâches plus simples (p.ex. vitesse motrice). Des études longitudinales ont également démontré que la qualité du sommeil en bas âge prédit le fonctionnement exécutif ultérieur de l'enfant (Friedman, Corley, Hewitt, & Wright, 2009; Gregory, Caspi, Moffitt, & Poulton, 2009). Des manipulations expérimentales, qui consistent à réduire le temps de sommeil de l'enfant pendant une ou plusieurs nuits, ont fourni des résultats similaires (Gruber et al., 2011; Randazzo, Muehlbach, Schweitzer, & Walsh, 1998; Sadeh, Gruber, & Raviv, 2003). Par exemple, Randazzo et al. (1998) ont démontré chez des enfants de 10 à 14 ans qu'une nuit de cinq heures, comparativement à 11 heures de sommeil, diminue la performance à plusieurs tâches cognitives, surtout aux tâches complexes requérant de la flexibilité mentale.

L'association entre le sommeil et le fonctionnement exécutif a également été étudiée chez des enfants d'âge préscolaire au développement typique. Auprès d'une cohorte longitudinale, il a été démontré que le sommeil à l'âge d'un an permet de prédire la performance à des mesures de FE à 18, 24 et 48 mois, mais pas le fonctionnement cognitif global (Bernier et al., 2013; Bernier et al., 2010). De façon similaire, Nelson, Nelson, Kidwell, James, et Espy (2015) ont démontré chez des enfants âgés de cinq ans que les problèmes de sommeil sont négativement corrélés aux performances aux tâches exécutives, mais pas à celles destinées à évaluer le fonctionnement cognitif global. Tous ces résultats soulignent la vulnérabilité des fonctions de haut niveau aux perturbations de sommeil, notamment chez les jeunes enfants dont les FE sont en pleine croissance.

Sommeil et fonctions exécutives après un TCC. Un nombre limité d'études se sont intéressées au lien entre le sommeil et les FE post-TCC. Étant donné qu'un TCC peut compromettre les FE, et que le sommeil favorise leur bon fonctionnement, la présence de perturbations de sommeil post-TCC pourrait exacerber les difficultés exécutives. Une étude réalisée auprès d'adultes ayant subi un TCC a révélé que les mauvais dormeurs commettaient davantage d'erreurs que les bons dormeurs à une épreuve d'attention soutenue (Bloomfield, Espie, & Evans, 2010). Dans une étude plus récente, les adolescents présentant de la somnolence diurne, telle que rapportée par leurs parents, avaient davantage de difficultés exécutives au quotidien (Osorio et al., 2013). Shay et ses collègues (2014) se sont intéressés au lien entre le sommeil et les FE spécifiquement chez les enfants d'âge préscolaire. Ils ont comparé des enfants âgés entre trois et six ans ayant subi un TCC (léger complexe/modéré ou sévère) ou une BO. Les parents ont complété des questionnaires portant sur les habitudes de sommeil et le fonctionnement exécutif quotidien de l'enfant, alors que les enfants ont complété une batterie de tests cognitifs (p. ex. mémoire, langage, fonctions exécutives). Les perturbations du sommeil rapportées par les parents n'étaient pas associées aux performances des enfants aux épreuves neuropsychologiques à 6, 12 et 18 mois post-blessure. Toutefois, il est à noter que les enfants ayant subi un TCC sévère et dont les parents notaient des difficultés de sommeil, avaient tendance ($p = .054$) à moins bien performer à une mesure d'inhibition et de flexibilité 6 et 12 mois après la blessure. Enfin, les parents qui rapportaient des difficultés de sommeil chez leur enfant rapportaient également un fonctionnement exécutif plus faible au quotidien. Toutefois, cette association n'était pas spécifique aux enfants ayant subi un TCC, se retrouvant à la fois dans le groupe BO et le groupe TCC.

Objectifs et hypothèses

L'objectif général de la thèse était d'examiner le sommeil et le fonctionnement exécutif six mois après un TCCL chez des enfants d'âge préscolaire, étant donné leur sous-représentation dans la littérature. Le corps de la thèse est constitué de deux articles empiriques, et deux autres articles pertinents au sujet de recherche sont présentés en annexes.

Le premier article visait à étudier le sommeil des enfants d'âge préscolaire ayant subi un TCCL entre 18 et 60 mois. Ils ont été comparés à des enfants ayant subi une blessure orthopédique (BO) et des enfants au développement typique. Des mesures de nature subjective (questionnaire standardisé) et objective (actigraphie) ont été utilisées en complémentarité pour évaluer le sommeil six mois après la blessure. Il était attendu que les enfants ayant subi un TCCL présenteraient davantage de problèmes de sommeil tels que rapportés par les parents au questionnaire, ainsi qu'un sommeil de plus courte durée et de qualité moindre, tels que mesurés par l'actigraphe, que les enfants des deux groupes contrôles. Un second objectif était d'identifier les facteurs (démographiques, pré-blessures et péri-blessures) qui contribuent à l'émergence de perturbations de sommeil après un TCCL préscolaire. Compte tenu de la littérature limitée sur ce sujet, les analyses étaient exploratoires.

Le deuxième article de la thèse avait pour but d'évaluer l'impact d'un TCCL sur les FE six mois après la blessure auprès de la même cohorte d'enfants d'âge préscolaire. Il était attendu que les enfants du groupe TCCL obtiendraient des performances inférieures aux tâches exécutives (inhibition et flexibilité) lorsque comparés au groupe d'enfants ayant subi une BO. De plus, cet article visait à évaluer la contribution du sommeil au fonctionnement exécutif après un TCCL. Sachant que le sommeil joue un rôle dans le fonctionnement exécutif au sein des populations normatives, un rôle modérateur du sommeil était attendu dans la relation entre le TCCL et le fonctionnement exécutif, de sorte que les enfants ayant subi un TCCL et dont le sommeil était perturbé, auraient une performance inférieure aux tâches de FE.

Les données présentées dans cette thèse s'inscrivent dans une étude longitudinale prospective plus large qui s'intéresse aux diverses conséquences d'un TCC préscolaire (Projet LION). Les analyses présentées se concentrent sur le sommeil et le fonctionnement exécutif, toutefois, les résultats en lien avec d'autres domaines sont rapportés ailleurs (Bellerose et al., 2017; Degeilh et al., 2018; Gagner, Dégeilh, Bernier, & Beauchamp, 2019; Gagner et al., 2017; Lalonde et al., 2018; Lalonde, Bernier, Beaudoin, Gravel, & Beauchamp, 2019; Tuerk et al., 2020).

CHAPITRE II : Article 1

Predictors of Sleep Outcomes Following Mild Traumatic Brain Injury in Preschoolers: Subjective and Objective Assessment of Outcome

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Abstract

***Objectives**:* To investigate sleep and its predictors in preschoolers with mild traumatic brain injury (mTBI). ***Participants and procedure**:* The sample included 225 children, aged 18 to 60 months, divided into three groups: children with accidental mTBI (*n* = 85), children with orthopedic injury (*n* = 58), and typically developing children (*n* = 82). Retrospective reports of preinjury sleep and family functioning were obtained as part of a baseline assessment at the time of recruitment. Parental ratings of sleep problems were collected six months postinjury on the full sample, and actigraphy data were collected on a subset of children. Demographic, preinjury and periinjury factors were examined as potential predictors of sleep outcomes. ***Results**:* No group differences were found in ratings of sleep problems or for nighttime sleep duration and sleep efficiency, as measured by actigraphy. Besides, preexisting sleep disturbances and brain injury resulting in alteration of consciousness were identified as predictors of poorer sleep in the mTBI group. ***Conclusion**:* Although mTBI did not result in group-level sleep disturbances six months postinjury, the findings suggest that pre-morbid and injury-related factors place some children at risk for poorer sleep after mTBI. These factors should be documented so clinicians can intervene early.

Keywords : actigraphy; concussion; pediatric; sleep; traumatic brain injury.

Introduction

Approximately 100-300 children per 100,000 sustain traumatic brain injury (TBI) annually, making TBI a leading cause of mortality and disability in children worldwide (Cassidy et al., 2004; Hawley, Ward, Long, Owen, & Magnay, 2003). The consequences of pediatric TBI on daily behavioral and cognitive functioning have been extensively documented (Beauchamp & Anderson, 2013; Catroppa, Anderson, Beauchamp, & Yeates, 2015; Garcia, Hungerford, & Bagner, 2015; Li & Liu, 2013). However, relatively few studies have investigated the nocturnal effects of childhood TBI, despite the fact that disturbed sleep is one of the most common complaints (Hooper et al., 2004).

Studies show that children with TBI exhibit more sleep problems than healthy children (Kaufman et al., 2001; Pillar et al., 2003) or those with orthopedic injuries (Beebe et al., 2007; Tham et al., 2012). Fragmented sleep, longer sleep latency and excessive daytime sleepiness are the most commonly reported sleep-wake disturbances after child TBI (Gagner, Landry-Roy, Lainé, & Beauchamp, 2015). Although these sleep difficulties have mainly been documented in the acute postinjury period, there is evidence that they can persist for several years (Beebe et al., 2007; Tham et al., 2012).

Sleep disturbances are generally more pronounced in children with moderate and severe TBI (Beebe et al., 2007; Tham et al., 2012), but they may also manifest themselves after mild TBI (mTBI; Blinman, Houseknecht, Snyder, Wiebe, & Nance, 2009). To date, sleep difficulties after childhood mTBI have been the focus of little sleep research, even though mild injuries account for 90% of TBI (Crowe, Babl, Anderson, & Catroppa, 2009). In addition, few studies have targeted preschoolers (0–5 years), despite the high prevalence of TBI in this age group (McKinlay et al., 2008). To our knowledge, only one sleep study has focused specifically on preschoolers. The authors observed that children with moderate or severe TBI display more sleep problems according to their parents than orthopedic controls six months postinjury (Shay et al., 2014).

The lack of sleep research in younger children with TBI is concerning considering that some of the most important developments in sleep patterns occur before the age of five (Acebo et al., 2005; National Sleep Foundation, 2004). In addition, there is a consensual body of evidence showing that a sufficient amount of good quality sleep is necessary for healthy development during childhood. Adequate sleep is essential for the development of metabolic and somatic functions (Hobson & Pace-Schott, 2002), and plays an important role in children's cognitive, behavioral and emotional development (Sadeh, 2007). An alteration in the amount or quality of sleep can lead to adverse consequences in many areas of child development, as well as family well-being (Beebe, 2011; Dahl & El-Sheikh, 2007). In healthy children, sleep difficulties have been shown to impact cognitive and academic performance (Dewald, Meijer, Oort, Kerkhof, & Bogels, 2010; Sadeh, 2007). They are also commonly associated with internalizing and externalizing behavior problems (Astill, Van der Heijden, Van Ijzendoorn, & Van Someren, 2012). Given that children with TBI are already at increased risk for cognitive and behavioral difficulties (Garcia et al., 2015), sleep disturbances could exacerbate these problems postinjury (Shay et al., 2014).

Individual differences may contribute to the presence of sleep problems after TBI, and research in adults has begun to identify these (Rao et al., 2008). However, little is known of the predisposing and precipitating factors associated with sleep disturbances post-TBI in children. In the general pediatric population, psychosocial problems and difficult temperament have been identified as risk factors for sleep problems (Atkinson, Vetere, & Grayson, 1995; Owens-Stively et al., 1997). Parenting practices (e.g., lack of routine) and parental functioning (e.g., parenting stress) can also contribute to the occurrence of sleep disturbances (Acebo et al., 2005; Byars, Yeomans-Maldonado, & Noll, 2011; Owens-Stively et al., 1997). However, it is not known whether the same risk factors apply to children with TBI. So far, one study conducted in children with TBI has identified pain, psychosocial problems and being female as predictors of sleep problems (Tham et al., 2012). More research is needed to identify risk factors of sleep disturbances after pediatric TBI so that clinicians can carefully monitor children at high risk and intervene during the early course of recovery.

The scarce literature available on sleep disturbances in children with TBI is limited by a number of methodological issues (Gagner et al., 2015). First, few studies have used adequate control groups to differentiate the effects of brain injury from more general injury-related factors. Moreover, studies have relied primarily on subjective sleep assessment methods (Bélanger, Simard, Bernier, & Carrier, 2014). Among the studies that have used objective measures, such as polysomnography or actigraphy, none have included preschoolers with TBI. Therefore, the first objective of this study was to assess the sleep of preschoolers (0–5 years) with mTBI and compare it to that of typically developing children (TDC) and children with orthopedic injuries (OI). Two control groups were included to take into account injury-related experiences and preinjury factors (OI), and to enable comparison with uninjured children to which children with TBI are compared in daily life (TDC). We assessed sleep with both subjective (parental questionnaire) and objective (actigraphy) measures of sleep. This approach allowed us to gather qualitative and quantitative data, and to document both sleep problems and sleep-wake patterns. It was expected that children with mTBI would display more sleep problems as reported by parents, along with shorter nighttime sleep duration and poorer sleep efficiency, as measured by actigraphy, than the OI and TDC groups. The second objective was to study potential predictors of sleep outcomes following early mTBI. Given the limited literature on the topic, the analyses were exploratory in nature. First, we examined basic demographic characteristics (age, sex, socioeconomic status, parental education, ethnicity). We also included preinjury sleep characteristics, as these are usually stable across time (Jenni, Molinari, Caflisch, & Largo, 2007), and preinjury family factors (parenting stress, relationship adjustment, family functioning), given that they are related both to TBI outcomes and sleep in the general population (El-Sheikh, 2011; Taylor et al., 2001). Finally, we considered clinical features (Glasgow coma score [GCS], the number of neurological signs, alteration of consciousness [AOC], post-concussive symptoms [PCS]) to document the association between injury factors and sleep post-TBI.

Method

The data presented here constitute a sub-study of a larger prospective longitudinal cohort study investigating cognitive and social outcomes of preschool TBI, which was approved by the local ethics review board.

Participants

The sample included 225 children divided in three groups: accidental mTBI ($n = 85$), accidental orthopedic injury (OI, $n = 58$) and typically developing children (TDC, $n = 82$).

Inclusion criteria for the mTBI group were: (*a*) age at injury between 18 and 60 months; (*b*) closed accidental TBI leading to an emergency department consultation with a Glasgow coma score between 13 and 15, and at least one of the following symptoms: persistent vomiting (≥ 3), excessive 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; and (*c*) child and at least one parent fluent in English or French.

Inclusion criteria for the OI group were: (*a*) age at injury between 18 and 60 months; (*b*) limb trauma leading to a final diagnosis of fracture, sprain, contusion, laceration, or any other trauma to an extremity; and (*c*) child and at least one parent fluent in English or French. Injury characteristics for the mTBI and OI groups are detailed in Table 1.

The inclusion criteria for the TDC were: (*a*) age between 24 and 66 months at time of recruitment (to ensure that the three groups were comparable at time of assessment); and (*b*) child and at least one parent fluent in English or French.

The following exclusion criteria were applied to all participants: (a) diagnosed congenital, neurological, developmental, psychiatric, or metabolic condition; (b) less than 36 weeks of gestation; (c) prior TBI.

Procedure

Children with mTBI and OI were recruited in an urban tertiary care pediatric emergency department between 2011 and 2015. A research nurse approached eligible children and obtained their verbal consent to be contacted by the research coordinator. Families who consented to participate were mailed sociodemographic and preinjury questionnaires (Time point 0; T0). The primary caregiver (92% mothers) was asked to answer the questionnaires based on their child's functioning *prior* to the injury to provide baseline information. Six months later (M = 6.77, SD = 1.02), parents were asked to complete the same questionnaires along with a post-concussive symptoms questionnaire, and children completed a 3-hour assessment as part of the larger longitudinal project (Time point 1; T1). In addition, a case report form was completed by a research nurse.

Children in the TDC group were recruited in local daycare centers. Given the absence of injury, children were invited for assessment and parents completed questionnaires as soon as possible after recruitment (T1).

A subset of children ($n = 91$) from the larger cohort study were offered to wear an actigraph (the sleep sub-study was introduced after the initial start of recruitment). There were no differences between those who were offered participation in the sleep sub-study and those who were not in terms of age ($t(223) = -0.01$, $p = .99$), sex ($t(223) = 0.35$, $p = .73$) or socioeconomic status ($t(212) = 0.53$, $p = .60$). Of the 91 families to whom actigraphs were offered, six families refused participation (either the parent or the child refused).

Measures

Questionnaires

Case Report Form. Information obtained from medical files for the mTBI group included: cause of the accident, lowest GCS, alteration of consciousness (AOC, defined as the presence of either confusion or loss of consciousness), presence of neurological signs and symptoms. For children with OI, the cause of the accident and diagnosis were documented.

Sociodemographic Questionnaire. This in-house questionnaire provides demographic information such as age, ethnicity, parental education (average of both parents' highest educational attainment, ranging from 1= doctoral level, to 8 = fewer than 7 years of school), and socioeconomic status (SES, calculated using the Blishen Socioeconomic Index; Blishen, Carroll, & Moore, 1987).

Parental Stress Index (PSI; Abidin, 1995). The PSI Parental distress subscale is a 12-item self-report questionnaire that assesses stress associated with the role of parent (e.g., perceived competence). Each item is rated on a 5-point scale, and a higher score indicates a higher level of parenting stress.

Family Assessment Device (FAD; Epstein, Baldwin, & Bishop, 1983). The General functioning scale from the FAD assesses overall family functioning. Each of the 12 items is rated on a 4-point scale, and a higher score indicates poorer family functioning.

Dyadic Adjustment Scale (DAS; Spanier, 1976). The DAS is a 4-item questionnaire that measures overall couple satisfaction. Items are answered on a 6-point scale, and a higher score indicates higher relationship satisfaction.

Post-concussive Symptom Interview (PCS-I; Mittenberg, Wittner, & Miller, 1997). The PCS-I assesses 15 cognitive, somatic, sleep and affective post-concussive symptoms (PCS). Parents must say if the symptoms were present or absent during the preceding week and the past six months.

Sleep measures

Child Behavior Checklist (CBCL), 1.5-5 year version (Achenbach & Rescorla, 2001). The 7-item Sleep scale from the CBCL documents sleep problems. Each item is rated on a 3-point scale (0 = Not true, 1 = Somewhat or sometimes true, 2 = Very true or often true). Following the recommendation of Thurber and Sheenan(Thurber & Sheehan), raw scores were used in statistical analyses.

Actigraphy and sleep diary. Children were asked to wear an Actiwatch 2 Actigraph (Phillips Respironics) for five consecutive days and nights as recommended by Acebo and colleagues (1999). To corroborate actigraphy data and identify potential artefacts, parents completed a sleep diary for the five days during which the child wore the actigraph. They were asked to indicate for each half-hour of the day whether the child was awake or asleep. They also indicated where the child was sleeping and reported any unusual events (e.g., illness). When the child was ill, not wearing the actigraph or co-sleeping, nights were excluded on a case-by-case basis. Actigraphy data were collected in 1-min epochs and analyzed using the Phillips Respironics Actiware software version 5.70. Sleep onset and sleep offset were determined based on visual examination of the actogram and guided by the diary. Data were analysed using the manufacturer's scoring algorithm set at the high sensitivity threshold (ACT80), which has been shown to be appropriate for preschoolers (Bélanger, Bernier, Paquet, Simard, & Carrier, 2013; Meltzer, Walsh, Traylor, & Westin, 2012). Two actigraphic variables were derived and averaged across the available assessment period: nighttime sleep duration (total number of minutes from sleep onset to sleep offset that were scored as sleep) and sleep efficiency (sleep minutes at night / (sleep minutes at night + wake minutes at night) * 100).

The actigraph was usually worn on the non-dominant wrist, but when the child felt uncomfortable, parents were told that the actigraph could be worn on the ankle. Consistent with a previous study in preschoolers (Bélanger et al.), there was no significant location difference for nighttime sleep duration ($t(52) = -1.31$, $p = .20$) or sleep efficiency ($t(52) = 1.36$, $p = .18$). Valid actigraphic data were available for five nights for 30 participants, for four nights for 10 participants, for three nights for 10 participants, and for two nights for 4 participants. Data were missing at random for the following reasons: the actigraph was worn but the parent did not complete or return the sleep diary ($n = 3$), the actigraph was worn but potential artefacts were identified ($n = 1$), the child refused to wear the actigraph for more than two days ($n = 23$), the child co-slept with someone ($n = 3$) or was ill ($n = 1$) throughout the entire data collection.

Statistical Analyses

Descriptive analyses were first performed to screen for violations of normality. Then, group comparisons were conducted on demographic variables (age, sex, SES, parental education, ethnicity) and family characteristics (preinjury and postinjury PSI, FAD, DAS) to ensure that groups were comparable. For preinjury family characteristics, individuals with mTBI were compared only to those with OI since no preinjury data was available for TDC. Analysis of variance (ANOVA) and independent sample *t* tests were used for continuous variables, and chi-square tests were conducted for categorical variables.

To investigate group differences on sleep outcomes (CBCL Sleep Scale, nighttime sleep duration and sleep efficiency), three analyses of covariance (ANCOVA) were performed. Age and sex were systematically included as covariates to control for known variations in sleep patterns (Biggs, Lushington, James Martin, van den Heuvel, & Declan Kennedy, 2013).

To identify predictors of sleep outcomes in the mTBI group, hierarchical regression analyses were conducted. Correlations were first run among all potential predictors and sleep outcomes (CBCL Sleep scale, nighttime sleep duration, sleep efficiency) to identify possible multicollinearity and select predictors to include in the regression models. Variables significantly correlated with any of the three sleep outcomes were included in each of the three models. Demographic characteristics (age at time of assessment, sex, ethnicity, SES, parental education) were entered in the first block to control for unmodifiable demographic factors. Given that sleep patterns vary across age and sex, they were both controlled for in the first block, regardless of whether correlations with the sleep variables were significant or not. To investigate the additional contribution of preinjury functioning, children's initial sleep and family characteristics (CBCL Sleep scale, PSI, FAD, DAS measured at T0) were entered in the second block. Finally, injury characteristics (lowest GCS, number of neurological signs, AOC, PCS-I scores) were entered in the third block to determine whether TBI markers explain sleep outcomes above and beyond demographics and preinjury characteristics.

To addresses multiple comparisons, a conservative alpha of .016 was used to assess significance in the ANCOVA and the regression analyses (0.05 divided by 3 outcomes); for all other analyses, an alpha of .05 was used. Effect sizes are reported using Cohen's *d* and partial eta squared for continuous data, and Cramer's *V* for categorical data.

Results

Final sample

Information on recruitment and follow-up are presented in Figures 1 and 2. For the mTBI and OI groups, there was no difference in terms of age at injury (mTBI: $t(236) = 0.83$, $p = .41$); OI: $t(238)= 0.67$, $p = .51$) and sex (mTBI: X^2 (1, $N = 239$) = 0.03, $p = .86$; OI: X^2 (1, $N = 240$) = .18, $p = .68$) between those who participated in the study and those who refused. Similarly for the TDC group, there was no difference in terms of age at recruitment ($t(107) = -0.40$, $p = .69$) and sex (X^2 (1, $N = 110$) = 3.48, $p = .06$) between those who participated in the study and those who refused.

We also examined attrition. There was no difference in terms of age at injury (mTBI: $t(104) = -0.25$, $p = .80$); OI: $t(82)= -1.19$, $p = .24$) and sex (mTBI: X^2 (1, $N = 106$) = 0.12, $p = .73$; OI: X^2 (1, $N = 84$) = .01, $p = .91$) between those who dropped out and those who maintained their participation in the two trauma groups. In addition, there was no age at recruitment ($t(82) = 1.82$,

p = .07) or sex differences (X^2 (1, N = 84) = 1.86, p = .17) between those who dropped out and those who did not in the TDC group.

Main analyses

As shown in Table 2, the three groups did not differ in terms of demographics and family characteristics. Group comparisons of sleep outcomes are presented in Table 3. After controlling for age and sex, there was no significant difference among the three groups for the CBCL Sleep scale, or for nighttime sleep duration and sleep efficiency as measured by actigraphy.

Table 4 presents the zero-order correlations among all the predictors and sleep outcomes in the mTBI group. As expected, parental education was significantly correlated with socioeconomic status (r = -.54, p < .01), such that higher educational attainment was related to higher SES. As also shown in Table 2, all the preinjury questionnaires completed by the primary caregiver (CBCL, PSI, FAD, DAS) were significantly inter-correlated (r = .25 to .81). Regarding the sleep outcomes, the CBCL Sleep scale was not correlated with actigraphy-derived variables (r = -.13 and -.23, p > 0.05), suggesting that these instruments measure distinct aspects of sleep.

The results of the hierarchical regression analyses are presented in Table 5. The standardized beta coefficients shown are those in the final models. Despite being significantly correlated with sleep outcomes, the preinjury PSI was excluded from the regression analyses to avoid multicollinearity given its elevated variance inflation factors (VIF = 4 to 7.2). There was no indication of possible collinearity among all the other independent variables (VIF values < 10, VIF averages ≤ 1; Myers, 1990). As shown in Table 5, neither age nor sex predicted any of the sleep outcomes. Among the preinjury characteristics, preinjury CBCL Sleep scale predicted postinjury CBCL Sleep scale (β = 0.68, p < .016), nighttime sleep duration (β = -0.46, p < .016) and sleep efficiency (β = -0.73, p < .016), such that preexisting sleep problems predicted more subsequent sleep problems, a shorter nighttime sleep duration and poorer sleep efficiency. The analyses also revealed that AOC contributed to predicting actigraphy-derived nighttime sleep duration (β =-0.52, $p < .016$) and sleep efficiency (β = -0.79, $p < .016$) above and beyond preinjury characteristics. As such, mTBI resulting in AOC contributed to predicting reduced nighttime sleep duration and lower sleep efficiency.

Discussion

This is the first study to assess sleep using both subjective and objective instruments in preschoolers with mTBI. Contrary to our hypothesis, primary caregivers of children with mTBI did not report greater sleep problems on the CBCL Sleep scale than did those of the two control groups six months postinjury. In addition, when looking at actigraphy-derived nighttime sleep parameters, no group effects were found for nighttime sleep duration and sleep efficiency. In a previous study, a similar lack of findings was reported for school-aged children with mTBI compared to those with OI six months postinjury on actigraphy measures (Milroy, Dorris, & McMillan). However, other studies in older children with mTBI described elevated sleep disturbances (Blinman et al., 2009; Hooper et al., 2004; Kaufman et al., 2001; Korinthenberg, Schreck, Weser, & Lehmkuhl, 2004; Pillar et al., 2003). Inconsistent findings in the scarce literature available may be due to heterogeneous methodology (e.g., assessment time after injury, sleep measures, age range, control group). Notably, sleep was assessed six months after mTBI in the current study, whereas previous reports have mainly targeted the acute injury period (Blinman et al., 2009; Hooper et al., 2004; Korinthenberg et al., 2004), during which PCS are more pronounced (Yeates et al., 2009). We cannot rule out the possibility that children in the current sample exhibited sleep difficulties shortly after the injury, which then resorbed prior to the six-month time point. Future studies should use longitudinal designs to examine trajectories of sleep disturbances from the acute to chronic stages.

Although no differences were found at the group level, some children demonstrated poorer sleep than others. A further novel contribution of this work is the identification of pre- and periinjury characteristics associated with sleep outcomes in the mTBI group. First, significant bivariate correlations were found between preinjury family factors and sleep outcomes. Parents were more likely to report sleep difficulties on the CBCL Sleep scale if they had lower levels of family functioning, poorer marital satisfaction and elevated parenting stress before the injury. Poor family functioning and elevated parenting stress were also related to longer nighttime sleep duration. However, the multivariate prediction model identified only preexisting sleep disturbances as a significant unique predictor of sleep difficulties postinjury. When examining the actigraphy findings, preexisting sleep disturbances and mTBI resulting in alteration of consciousness (AOC) were significant predictors of both actigraphy-derived nighttime outcomes. Children who exhibited elevated sleep problems before the injury were more likely to have subsequent sleep problems, a shorter nighttime sleep duration and poorer sleep efficiency six months postinjury. Moreover, AOC contributed to predicting reduced nighttime sleep duration and lower sleep efficiency above and beyond preinjury sleep difficulties. After accounting for age, sex and preinjury characteristics, AOC explained a significant 20% of variance in nighttime sleep duration and 46% of variance in sleep efficiency. Given that AOC is common in moderate-severe TBI, we can speculate that the incidence of sleep difficulties may be higher in more severely injured samples. Indeed, Beebe et al. (2007) reported that children with severe TBI display a significant increase in sleep difficulties after the injury compared to children with milder TBI. In addition, previous work in pediatric TBI has shown that loss of consciousness predicts worse outcomes after TBI (McDonald et al., 1994; Prasad, Ewing-Cobbs, Swank, & Kramer, 2002). Further research is needed to understand how AOC contributes to sleep disturbances. Studies could investigate the role of the reticular activating system, as it may be involved in both sleep problems and altered consciousness after TBI (Blyth & Bazarian, 2010; Evans, 2002).

Several factors did not predict sleep outcomes. None of the demographic characteristics were associated with sleep outcomes. These results contrast with those of Tham et al. (2012) who found that females (2–17 years) were more likely to exhibit sleep disturbances post-TBI. The wide age range in their study prohibits direct comparison with our sample, but it is possible that mechanisms affecting sleep differ with developmental stage. Moreover, other than AOC, no injury markers were associated with sleep outcomes. This lack of association may be due to the poor sensitivity of clinical measures to detect injury variations that influence sleep. In particular, accurate assessment of PCS is one of the many challenges of studying preschoolers. Preverbal children may fail to communicate their symptoms, making the manifestations of some neurological signs (e.g., headaches) difficult to detect (Catroppa et al., 2015). Also, there is currently no validated measure of PCS for children under five years of age. We chose to administer the PCS-I, validated for children aged 5–18 years old (Sady, Vaughan, & Gioia, 2014), to explore post-concussive symptoms. However, efforts are needed to develop and validate tools to reliably document PCS in preschool children.

Together, our results indicate that preexisting sleep disturbances and TBI resulting in AOC place children at risk for poorer sleep after mTBI. Moreover, our results indicate that family factors can modulate children's sleep. Clinicians should be particularly vigilant in documenting sleep in children presenting with these characteristics, especially given that individuals with sleep problems are more prone to future TBI, which could lead to cumulative injuries (Faul, Xu, Wald, & Coronado, 2010; Owens, Fernando, & Mc Guinn, 2005).

A number of methodological limitations must be considered when interpreting the current results. First, our actigraphy results are limited by the modest sample size. Collecting actigraphy data in young children is challenging. Despite encouragements by parents, 28% of children in our sample refused to wear the actigraph, which inevitably reduced the sample size. Of note, however, this is the first study ever to document sleep in preschoolers with mTBI using an objective method. Second, we acknowledge the limitations of parental reports of sleep difficulties on the CBCL. Although frequently used, questionnaires are sensitive to respondent bias. Nevertheless, the inclusion of the CBCL sleep questionnaire is a cost-effective way to gather information on sleep complaints, which cannot be identified with actigraphy (Sadeh, 2015; Werner, Molinari, Guyer, & Jenni, 2008). Third, we did not assess pain, which has previously been identified as a predictor of sleep disturbances after TBI (Duclos et al., 2014; Tham et al., 2012). Despite these limitations, this study brings a significant contribution by documenting sleep after early mTBI and its predictors. Among the methodological strengths of the study are the inclusion of an OI comparison group, the use of both objective and subjective measures to comprehensively assess sleep, and a sample that was not selected on the basis of sleep disturbances. Future research with larger sample sizes should include additional measures of daytime sleep and conduct a more exhaustive assessment of risk factors for sleep disturbances post-TBI and investigate the mechanisms underlying their development. A better understanding of the factors predisposing, precipitating and perpetuating sleep disturbances could lead to early detection and better clinical management after pediatric TBI.

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Table 1

Injury characteristics

	mTBI *M (SD)*	OI *M (SD)*
Age at injury, mo	36.85 (11.62)	36.29 (18.23)
Cause of trauma, *n (%)*		
Car accident	2 (2.40)	-
Accidental fall	77 (90.60)	36 (62.10)
Other nonintentional accidents	6 (7.10)	22 (37.90)
Lowest Glasgow Coma Scale score	14.85 (0.48)	-
Number of neurological signs [a]	2.36 (1.40)	-
AOC, *n (%)*	29 (34.90)	-

Note. AOC = Alteration of consciousness.
[a] Neurological signs includes headaches, irritability, persistent vomiting, hematoma, drowsiness, dizziness, seizure, visual symptoms and balance/motor problems.

Table 2

Participant characteristics

	mTBI *M (SD)*	OI *M (SD)*	TDC *M (SD)*	F / t / X^2	p	η^2 / d / V
N	85	58	82			
Demographics						
Age at postinjury assessment	43.14 (11.61)	40.19 (11.12)	42.93 (11.53)	1.34	.27	0.01
Sex (male), *n (%)*	45 (52.90)	26 (44.80)	42 (51.20)	0.96	.62	0.07
Socioeconomic status	55.91 (13.65)	58.33 (13.64)	59.68 (11.97)	1.67	.19	0.02
Parental education	3.14 (1.15)	2.93 (0.94)	2.85 (0.83)	1.90	.15	0.02
Ethnicity (Caucasian), *n (%)*	71 (84.50)	44 (78.60)	66 (82.50)	0.82	.66	0.06
Family characteristics						
Preinjury PSI	2.13 (0.74)	1.96 (0.65)	-	1.36	.18	0.23
Postinjury PSI	2.03 (0.65)	1.97 (0.70)	2.07 (0.66)	0.43	.65	0.01
Preinjury FAD	1.67 (0.50)	1.61 (0.45)	-	0.70	.49	0.12
Postinjury FAD	1.59 (0.47)	1.67 (0.48)	1.56 (0.40)	0.92	.41	0.01
Preinjury DAS	4.08 (0.91)	3.92 (0.90)	-	1.04	.30	0.18
Postinjury DAS	4.03 (0.94)	4.02 (0.74)	4.10 (0.88)	0.21	.81	0.01

Note. DAS = Dyadic Adjustment Scale; FAD = Family Assessment Device, General functioning scale; PSI = Parenting Stress Index, Parental distress scale.

Table 3

Comparisons of sleep variables across the 3 participant groups

Sleep variables	mTBI *M (SD)*	OI *M (SD)*	TDC *M (SD)*	*F*	*p*	η^2
Postinjury CBCL Sleep scale	4.02 (2.86)	3.84 (3.30)	3.13 (2.59)	2.17	.12	0.02
Actigraphy						
Nighttime sleep duration, min	533.57 (48.69)	519.18 (25.37)	530.42 (48.00)	0.46	.64	0.02
Sleep efficiency, %	91.08 (4.61)	88.16 (6.76)	91.47 (2.41)	1.20	.31	0.05

Table 4

Zero-order correlations in the mTBI group among all main variables under study

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Age at postinjury ass.	.06	.08	-.07	-.07	-.11	.22	.02	.02	-.06	.28*	.07	.10	.03	-.02	.34	.18
2. Sex	-	.01	-.08	.13	.25*	.13	.12	-.08	-.11	.09	-.05	.09	.10	.13	.31	.26
3. Ethnicity		-	-.01	-.18	.03	.10	-.05	.04	-.21	-.02	.20	-.14	-.08	.05	-.02	-.21
4. Socioeconomic status			-	-.54**	.01	.01	.01	-.03	.11	.01	.12	.06	-.06	-.07	.01	.06
5. Parental education				-	.11	.02	.09	-.07	-.23*	-.07	-.05	-.05	.20	.07	-.16	-.24
6. Preinjury CBCL Sleep					-	.36*	.25*	-.28*	-.04	.09	-.11	.11	.05	.69**	-.43	-.44*
7. Preinjury PSI						-	.64**	-.62**	.04	-.07	.03	.20	.22*	.35**	.43*	.05
8. Preinjury FAD							-	-.81**	.12	-.04	-.12	.40**	.28*	.34**	.48*	.14
9. Preinjury DAS								-	-.21	.05	.09	-.19	-.24*	-.27*	-.20	-.01
10. Lowest GCS score									-	-.13	-.07	-.06	-.13	-.06	-.18	-.15
11. Number of neurol. signs										-	-.07	.08	.26*	.09	-.15	-.05
12. AOC											-	.01	-.06	-.14	-.46*	-.54**
13. PCS-I (last week)												-	.53**	.25*	-.36	-.14
14. PCS-I (since injury)													-	.17	-.10	-.16
15. Postinjury CBCL Sleep														-	-.23	-.13
16. Acti. nightime sleep dur.															-	.74**
17. Acti. sleep efficiency																-

Note: AOC = Alteration of consciousness; DAS = Dyadic Adjustment Scale; FAD = Family Assessment Device, General functioning scale; GCS = Glascow coma score; PCS-I = Post-concussive Symptom Interview; PSI = Parenting Stress Index, Parental distress scale.
* $p < .05$. ** $p < .01$.

Table 5

Summary of regression analyses predicting sleep outcomes

	Criterion		
Model	Adjusted R^2	ΔR^2	β
Postinjury CBCL Sleep scale			
1. Age at postinjury assessment	-0.02	0.01	0.05
Sex			-0.11
2. Preinjury CBCL sleep scale	0.47	0.50**	0.68**
Preinjury FAD			0.14
Preinjury DAS			0.02
3. AOC	0.47	0.01	-0.09
PCS-I (last week)			0.05
Actigraphy nighttime sleep duration			
1. Age at postinjury assessment	0.12	0.23	0.13
Sex			0.32
2. Preinjury CBCL Sleep scale	0.51	0.43**	-0.46**
Preinjury FAD			0.51
Preinjury DAS			0.39
3. AOC	0.75	0.20**	-0.52**
PCS-I (last week)			-0.19
Actigraphy sleep efficiency			
1. Age at postinjury assessment	-0.03	0.09	0.02
Sex			0.20
2. Preinjury CBCL Sleep scale	-0.03	0.22	-0.73**
Preinjury FAD			-0.14
Preinjury DAS			-0.04
3. AOC	0.62	0.46**	-0.79**
PCS-I (last week)			0.10

Note. AOC = Alteration of consciousness; DAS = Dyadic Adjustment Scale; FAD = Family Assessment Device, General functioning scale; PCS-I = Post-concussive symptom Interview.
** $p < .016$.

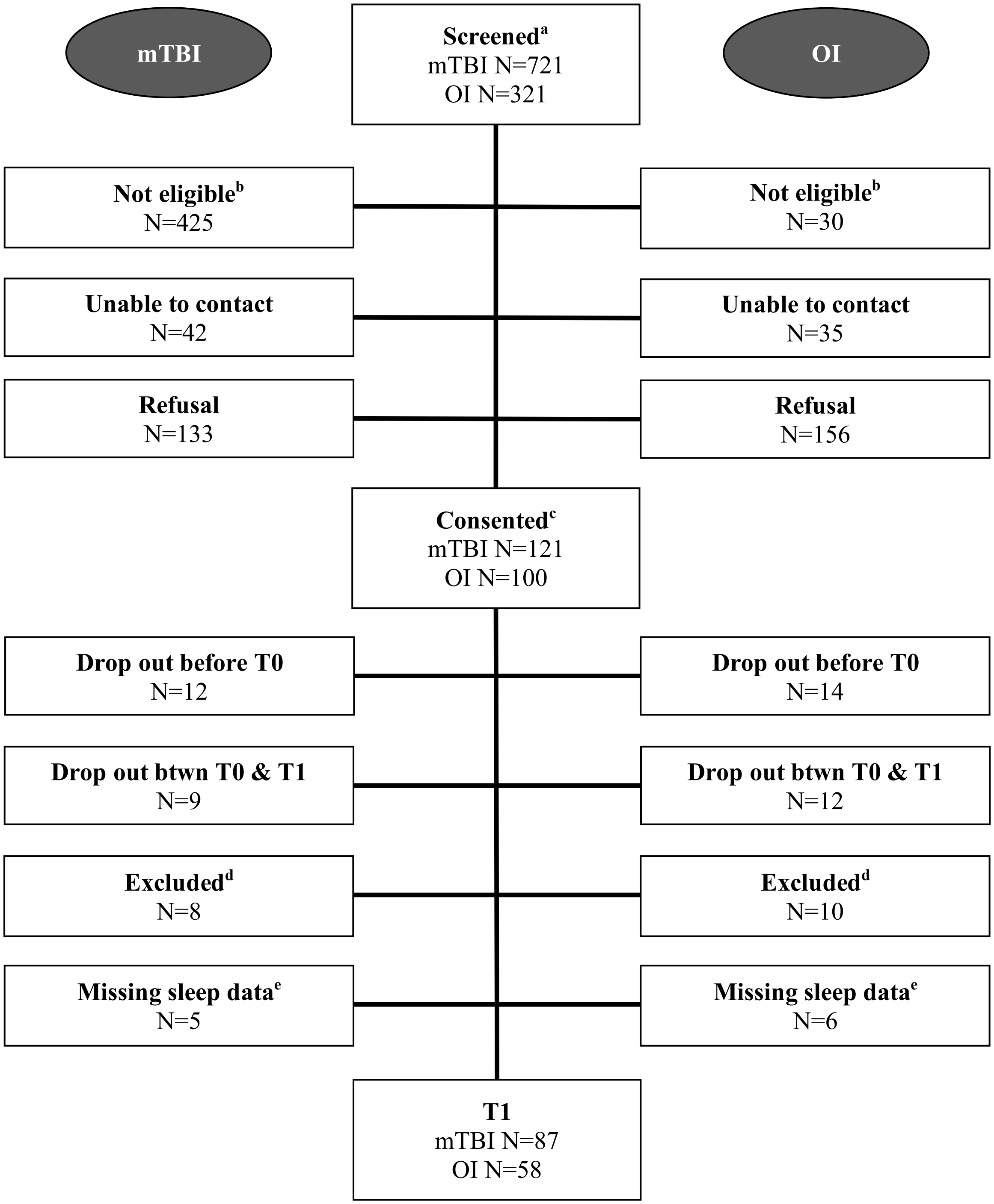

Figure 1. Recruitment and follow-up flowchart for the mTBI and OI groups. [a]The following emergency department diagnoses were considered for participation in the study: *mTBI group:* traumatic brain injury, head fracture, concussion, intracranial bleeding/haemorrhage, polytrauma; *OI group:* orthopaedic 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 at T1 because they did not satisfy an inclusion and/or exclusion criterion that had not been detected prior to testing. [e]*Missing sleep data* due to failure to return the T1 questionnaire booklet.

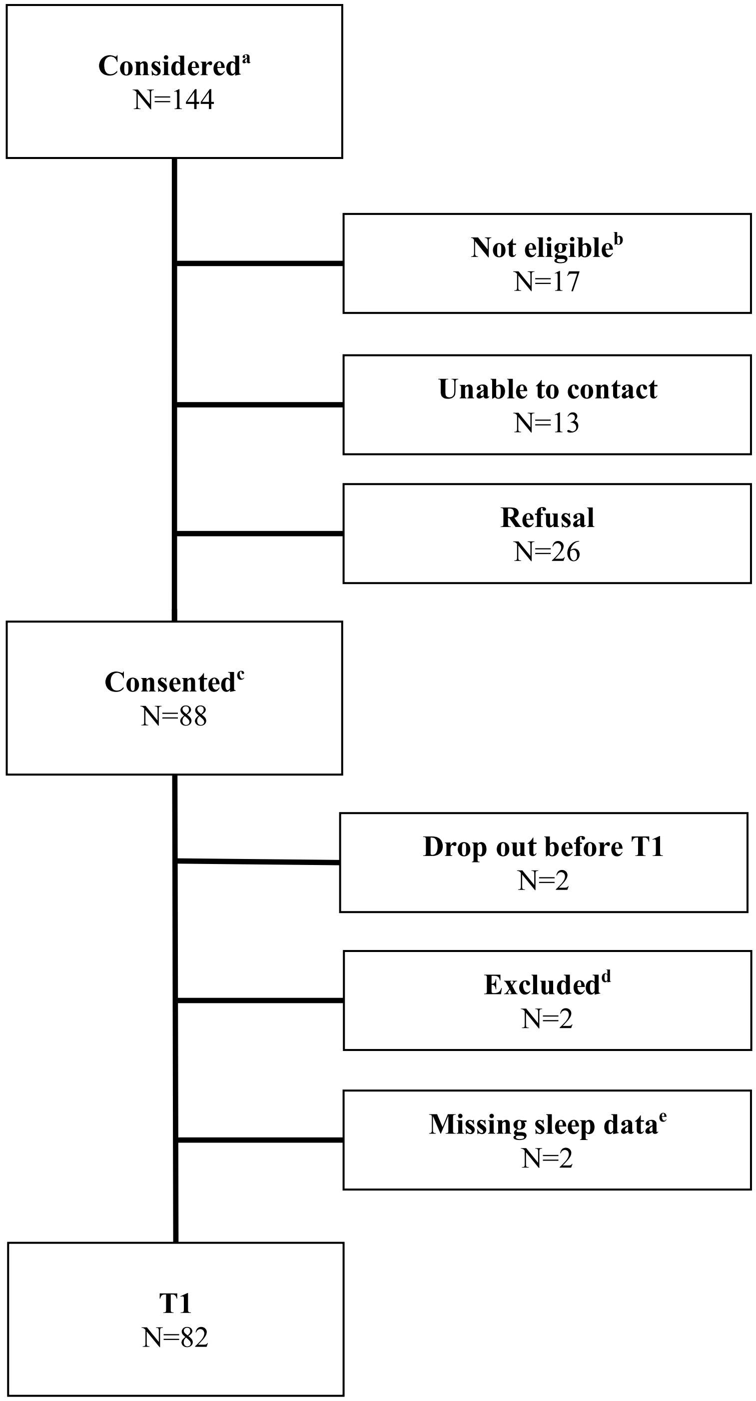

Figure 2. Recruitment and follow-up chart for the TDC group. [a]*Considered* refers to participants whose parents were given a study pamphlet at daycare and who gave their verbal consent to be contacted by the research coordinator. [b]Potential participants were not eligible because they did not satisfy an inclusion and/or exclusion criterion. [c]*Consented* refers to those participants whose parents signed a consent form. [d]These participants were excluded at T1 because they did not satisfy an inclusion and/or exclusion criterion that had not been detected prior to testing. [e]*Missing sleep data* due to failure to return the T1 questionnaire booklet.

CHAPITRE III : Article 2

Executive Functions and their Relation to Sleep following

Mild Traumatic Brain Injury in Preschoolers

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Abstract

***Objectives**:* Traumatic brain injury (TBI) sustained during childhood is known to impact children's executive functioning. However, few studies have focused specifically on executive functioning after preschool TBI. TBI has also been associated with sleep disturbances, which are known to impair executive functions in healthy children. The aim of this study was to investigate executive functions in preschoolers with mild TBI, and to determine the role of sleep in the links between TBI and executive functioning. ***Methods**:* The sample was drawn from a longitudinal study and included 167 children, aged 18 to 60 months, divided into 2 groups: children with accidental mild TBI (*n* = 84), and typically developing children (*n* = 83). Children were assessed 6 months post-injury on executive function measures (inhibition and cognitive flexibility) and sleep measures (actigraphy data and parental rating of sleep problems). ***Results**:* The two groups did not differ in their executive abilities. However, relative to controls, children with mild TBI and shorter nighttime sleep duration or increased sleep problems exhibited poorer executive functions. ***Conclusions**:* These results support a "double hazard" effect, whereby the combination of sleep disturbances and mild TBI results in poorer executive functions. The findings highlight the importance of assessing and monitoring the quality of sleep even after mild head injuries. Poor sleep may place children at risk for increased cognitive difficulties.

Keywords : brain injuries, executive function, sleep, child, cognition, preschool**.**

Introduction

Executive functions (EF) play a crucial role in early cognitive, behavioral and socio-emotional development (S. M. Carlson, Davis, & Leach, 2005; Isquith, Crawford, Espy, & Gioia, 2005). EF is an umbrella term used to describe the processes needed to achieve novel, purposeful and goal-directed action; these include, among others, inhibition, cognitive flexibility, planning and abstraction (Garon, Bryson, & Smith, 2008; Lezak, 1982). The development of EF has been linked in part to the maturation of prefrontal brain regions (Goldberg & Bougakov, 2005; Jacobs, Harvey, & Anderson, 2007; Wood & Smith, 2008). During the first five years of life, the rapid growth of prefrontal brain regions translates into significant progress in EF (P. Anderson, 2002; Durston & Casey, 2006; Garon et al., 2008; Tsujimoto, 2008). The preschool period is marked by the acquisition of core EF (e.g., inhibition, cognitive flexibility), while more complex skills (e.g., problem solving, goal setting, reasoning) develop in middle childhood and adolescence (P. Anderson, 2002; Vicki Anderson, 1998). Studies that have focused on mapping the developmental trajectories of EF indicate that earlier developing core EF underlie and predict more complex executive abilities (Collins & Koechlin, 2012; Diamond, 2013; Garon et al., 2008). As such, if the integrity of the brain is altered during early childhood, a critical time for the establishment and emergence of executive skills, there is likely to be increased risk for EF impairments and cumulative deficits.

Given that EF are mainly governed by prefrontal regions, they are particularly vulnerable to frontal insults, such as those typically observed after traumatic brain injury (TBI), which causes the brain to move back and forth within the skull due to accelerating and decelerating forces (Mustafa & Alshboul, 2013). Accordingly, EF deficits after pediatric TBI are well documented in school-aged children and adolescents (Levin & Hanten, 2005). Such executive deficits are generally more pronounced following moderate-severe TBI (Nadebaum, Anderson, & Catroppa, 2007), but in some cases, they may manifest after mild TBI (mTBI; Loher, Fatzer, & Roebers, 2014). However, only a handful of studies have investigated EF following TBI in early childhood. Those that have addressed the question report inhibition, flexibility and working memory deficits that are generally more pronounced after more severe injuries (Catroppa, Anderson, Morse, Haritou, & Rosenfeld, 2007; L. M. Crowe, Catroppa, Babl, & Anderson, 2013; Ewing-Cobbs, Prasad, Landry, Kramer, & DeLeon, 2004; Ganesalingam et al., 2011; Nadebaum et al., 2007).

Despite these results, several methodological issues preclude clear conclusions about the impact of preschool TBI on EF. First, some studies group preschoolers with school-age children, making it impossible to draw conclusion specific to the younger age group (Catroppa et al., 2007; Nadebaum et al., 2007). Others group accidental and inflicted TBI together (Ewing-Cobbs et al., 2004), though the two forms are associated with distinct brain pathology and psychosocial factors (Ennis & Henry, 2004; Keenan, Runyan, Marshall, Nocera, & Merten, 2004). Besides, some focus only on longer-term outcomes (e.g., middle childhood) of preschool injuries or do not standardize the time elapsed since the injury (Catroppa et al., 2007; L. M. Crowe et al., 2013; Nadebaum et al., 2007). Finally, some focus specifically on the effects of moderate-severe injuries, and do not include mTBI (Ewing-Cobbs et al., 2004; Ganesalingam et al., 2011), although mild injuries constitute the majority (about 90%) of TBI (Cassidy et al., 2004).

In addition to showing susceptibility to brain insults such as TBI, altered EF has been linked to broader disorders of biological functions, such as sleep disturbances. Beyond the negative effects of sleep problems on general cognitive functioning, substantive literature has identified EF as especially vulnerable to poor sleep. Although the underlying neuronal and neurochemical mechanisms of sleep-related EF dysfunction remain unclear, it has been suggested that the effect of poor sleep is more potent for EF because the prefrontal cortex is especially sensitive to sleep curtailment (Dahl, 1996; Horne, 1993; Jones & Harrison, 2001; Muzur, Pace-Schott, & Hobson, 2002). It is hypothesized that the prefrontal regions largely benefit from the regenerating role of sleep due to their intense activity in waking humans, and that their functioning essentially rests with proper sleep (Horne, 1993; Ingvar, 1979).

In typically developing school-aged children and adolescents, associations between poor sleep and EF impairments have been identified through both correlational studies (Friedman, Corley, Hewitt, & Wright, 2009; Gregory, Caspi, Moffitt, & Poulton, 2009; Sadeh, 2007; Sadeh, Gruber, & Raviv, 2002), and experimental sleep restriction paradigms (Gruber et al., 2011; Randazzo, Muehlbach, Schweitzer, & Walsh, 1998; Sadeh, Gruber, & Raviv, 2003). A small number of studies have investigated the association between sleep and EF in the preschool period. In a longitudinal study, sleep at one year of age was shown to predict EF performance at 18, 24 and 48 months of age, independently of general cognitive abilities and language skills (Bernier, Beauchamp, Bouvette-Turcot, Carlson, & Carrier, 2013; Bernier, Carlson, Bordeleau, & Carrier, 2010). Similarly, Nelson, Nelson, Kidwell, James, and Espy (2015) showed that sleep problems were negatively associated with subsequent performance on suppression inhibition and working memory tasks in a sample of typically developing preschoolers.

Despite growing literature on the effects of poor sleep and EF, few studies have been conducted in children with TBI. This is concerning given that children with TBI are at increased risk for sleep disturbances (Gagner, Landry-Roy, Laine, & Beauchamp, 2015), which could exacerbate putative post-injury EF impairments. The preschool period, marked by the development of core EF, is of particular interest since it witnesses the highest prevalence of TBI (L. Crowe, Babl, Anderson, & Catroppa, 2009; Hawley, Ward, Long, Owen, & Magnay, 2003). To our knowledge, only one study has examined the relation between sleep disturbances and EF in preschoolers with TBI of various severity at 6, 12 and 18 months post-injury (Shay et al., 2014). Most analyses failed to reveal significant associations between sleep disturbances and executive functions. However, the authors observed that children with severe TBI who experienced a high level of sleep disturbance tended to display poorer performance on inhibition and flexibility measures at 6 and 12 months post-injury, but this finding must be interpreted with caution as it only approached significance. In contrast, sleep disturbance was not associated with any of the other tests of cognitive ability included. Shay and colleagues (2014) also reported that children with more sleep problems demonstrated poorer executive functions in everyday situations, but this relation held across both TBI and control groups.

The first objective of the current study was to assess EF in preschoolers with mTBI. It was expected that children with mTBI would display poorer EF than typically developing controls. The second objective was to determine the role of sleep in the links between preschool mTBI and executive functioning. Given that sleep impacts EF in normative pediatric populations, it was expected that sleep would interact with mTBI in the prediction of EF, such that children with mTBI and poorer sleep would exhibit poorer EF.

Method

Participants

This study was approved by the institutional review board of Sainte-Justine Hospital and conducted in accordance with the Helsinki declaration. The sample included 167 children divided in two groups: children who sustained accidental mTBI (n = 84) and typically developing children (TDC, n = 83). The present sample was drawn from a broader longitudinal study investigating cognitive and social outcomes of preschool TBI (LION study). As part of this larger study, children who sustained orthopedic injuries (OI) were also recruited. However, they were not included in the current paper given that only a small proportion of OI had available sleep data. We confidently used TDC for the current analyses, having previously shown that the TDC and OI groups in the study had similar demographic profiles, development and medical history, behavioral and adaptive profiles, family functioning and cognition (M. H. Beauchamp, Landry-Roy, Gravel, Beaudoin, & Bernier, 2017).

Children with mTBI were recruited based on the definition reported by Osmond et al. (2010). Inclusion criteria were: (a) age at injury between 18 and 60 months; (b) closed accidental TBI leading to an emergency consultation with a Glasgow coma score (GCS) between 13 and 15, and at least one of the following symptoms: persistent vomiting (≥ 3), excessive 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; (c) child and at least one parent fluent in English or French. Injury characteristics are detailed in Table 1. Most mTBIs were caused by an accidental fall (93%), resulting in a GCS score of 15 in 88% of cases. The inclusion criteria for the TDC were: (a) age between 24 and 66 months at time of recruitment (to ensure that the two groups were comparable at time of assessment); (b) child and at least one parent fluent in English or French.

The following exclusion criteria were applied to all participants: (a) diagnosed congenital, neurological, developmental, psychiatric, metabolic or sleep condition; (b) less than 36 weeks of gestation; (c) prior TBI.

Procedure

Children with mTBI were recruited in an urban tertiary care pediatric emergency department between 2011 and 2015. A research nurse approached eligible children and obtained their verbal consent to be contacted by the research coordinator. Families who agreed to participate were mailed a sociodemographic questionnaire and pre-injury questionnaires (including the Child Behavior Checklist, see description below) immediately after consenting. Parents were asked to answer the questionnaires based on their child's functioning prior to the TBI to provide baseline information. Meanwhile, a standardized case report form was completed by the research nurse to ensure that children satisfied inclusion and exclusion criteria and to document clinical and injury-related details. Six months later (M = 6.65, SD = 0.86), parents were asked to complete the same questionnaire booklet and the Postconcussive Symptom Interview (see description below), and children completed a 3-hour neuropsychological assessment.

Children in the TDC group were recruited in local daycare centers. Given the absence of injury, children were invited for assessment as soon as possible after recruitment, and parents completed the sociodemographic questionnaire, the questionnaire booklet and the Postconcussive Symptom Interview.

At the end of the neuropsychological assessment, a subset of children (n = 68; 33 mTBI and 35 TDC) were asked to wear an actigraph to assess their sleep objectively. Actigraphs could not be proposed to all participants as the sleep sub-study was introduced after the initial start of recruitment. After the sub-study was introduced, all participants were offered an actigraph, unless they lived outside the urban area, which was not easily serviced by courier. There were no differences between those who were offered participation in the sleep sub-study and those who were not in terms of age ($t(165) = 0.20$, p = .84), sex (X^2 (1, N = 167) = 0.67, $p = .42$) or socioeconomic status ($t(155) = -0.144$, $p = .89$). Of the 68 families to whom actigraphs were offered, 2 families refused participation (either the parent or the child refused).

Measures

Participant and injury characteristics

Sociodemographic questionnaire. This questionnaire provides demographic information such as age, ethnicity, family constellation, parent's education and occupation. Parental education was obtained by averaging both parents' highest educational attainment, ranging from 1 (doctoral level) to 8 (less than 7 years of school). When parental occupation and/or highest educational attainment was available for only one parent, or in the case of single parent families, no average was computed. If a child lived with one biological parent and a step-parent, we used the step-parent's information. in the average. Parent occupation allows calculation of the Blishen Socioeconomic Index (Blishen, Carroll, & Moore, 1987). In light of their intercorrelation ($r = .51$, $p < .001$), parental education and Blishen scores were standardized and averaged into a global family socioeconomic status (SES) index.

Case Report Form. Information obtained from medical files for the mTBI group included: cause of the accident, lowest GCS, presence of neurological signs (headaches, irritability, persistent vomiting, hematoma, drowsiness, dizziness, seizure, blurred vision or hypersensitivity to light, and motor or balance difficulties) and alteration of consciousness (defined as the presence of either confusion or loss of consciousness).

Postconcussive Symptom Interview (PCS-I) (Mittenberg, Wittner, & Miller, 1997). The PCS-I assesses 15 cognitive, somatic, sleep, and affective post-concussive symptoms. Parents must say if the symptoms were present or absent during the preceding week.

Executive functions

Delay of Gratification (Beck, Schaefer, Pang, & Carlson, 2011). In this inhibition task, children must make a series of choices as to whether they want a smaller, immediate reward or a larger, delayed reward. Rewards consist of stickers, crackers and pennies presented in small plastic containers. There are three trials for each type of reward, for a total of nine trials. For example, the child must choose between a cracker to eat now, or six crackers to eat later "when all games are completed and you return home". One point is awarded every time the child selects the delayed reward for a maximum of nine points, and a higher score indicates better performance. This task has satisfactory test-retest reliability ($r = .76$; Beck et al., 2011).

Conflict Scale (Zelazo, 2006). This cognitive flexibility task consists of four levels of increasing difficulty (Categorization/Reverse Categorization, Dimensional Change Card Sort (DCCS)–Separated, DCCS–Integrated, and DCCS–Advanced), and children begin the task at the appropriate level for their age. Children are asked to categorize items, either plastic animals or cards, according to a rule, and if they succeed on five trials out of six, the rule is changed in a post-switch phase. For example, children are first instructed to sort cards depicting trucks and stars according to color (blue or red). Then, the experimenter announces that they will stop playing the "color game" and now play the "shape game". Children must then sort cards according to shape (truck or star), regardless of color. There are 12 trials per level, for a maximum of 48 points, and a higher score indicates higher cognitive flexibility. This measure has excellent test-retest reliability ($r = .94$; Beck et al., 2011).

Shape Stroop (Stephanie M. Carlson, 2005; Kochanska, Murray, & Harlan, 2000). In this task of inhibition and cognitive flexibility, children are first shown six cards depicting three fruits (three large and three small fruits) and asked to identify each fruit. Then, children are shown cards depicting a small fruit embedded in a large fruit (e.g., small banana embedded in a large orange), and asked to point to each small fruit (e.g., "show me the small banana"). A total of three cards are presented, for a maximum of three points, and a higher score indicates better performance.

Sleep measures

Child Behavior Checklist (CBCL), 1.5-5 year version (Achenbach & Rescorla, 2001). The CBCL is a parent-report questionnaire pertaining to children's behavioral difficulties and includes a Sleep scale that can be generated from seven items designed to document sleep problems; (1) "Does not want to sleep alone," (2) "Has trouble getting to sleep," (3) "Nightmares," (4) "Resists going to bed at night," (5) "Sleeps less than most children during day and/or night," (6) "Talks or cries out in sleep," and (7) "Wakes up often at night". Each item is rated on a 3-point scale (0 = Not true, 1 = Somewhat or sometimes true, 2 = Very true or often true), and a higher score indicates a higher level of sleep disturbances. Following the recommendation of Thurber and Sheehan (2012), raw scores were used in statistical analyses.

Although the specific CBCL Sleep scale has not been validated independently of the overall CBCL questionnaire, it shows good convergent validity (r = .39-.55) with other validated sleep scales, such as the Children Sleep Habit Questionnaire, the Sleep Disorders Inventory for Students and the Adolescent Sleep-Wake Cycle questionnaire (Becker, Ramsey, & Byars, 2015). The internal consistency of the 7-item Sleep scale in the current study was 0.73.

Actigraphy and sleep diary. Children were asked to wear an Actiwatch 2 actigraph (Phillips Respironics) for five consecutive days and nights. Actigraphy data were collected in 1-minute epochs, and data were analysed using the Phillips Respironics Actiware software version 5.70. The automated manufacturer's low sensitivity threshold algorithm (80 activity counts per epoch), which has been shown to be appropriate for preschoolers (Bélanger, Bernier, Paquet, Simard, & Carrier, 2013; Meltzer, Walsh, Traylor, & Westin, 2012), was used to determine minute-by-minute sleep-wake status.

To corroborate actigraphy data and identify potential artefacts, parents completed a sleep diary for the five days during which the child wore the actigraph. They were asked to indicate for each half-hour of the day whether the child was awake or asleep, and where he or she slept (e.g., child's bedroom, car). They were also instructed to document periods when the child did not wear the actigraph (e.g., bath) and to report any unusual events (e.g., illness). When the child had an unusual night, was not wearing the actigraph or co-sleeping, nights were excluded on a case-by-case basis. Furthermore, actigraphic data were discarded when they showed poor correspondence with the sleep diary or when no diary was available. Valid actigraphic data were available for five nights for 25 participants (11 mTBI and 14 TDC), for four nights for 8 participants (5 mTBI and 3 TDC), for three nights for 9 participants (4 mTBI and 5 TDC), for two nights for 4 participants (2 mTBI and 2 TDC), and for one night for 3 participants (3 mTBI).

Sleep onset and sleep offset were determined based on visual examination of the actogram and guided by the diary. Sleep onset was determined by starting to examine the actogram 30 minutes prior to the sleep onset reported in the diary. Similarly, the starting point was set 30 minutes after sleep offset, as indicated on the diary, to identify sleep offset. Two actigraphic variables were derived across the available assessment period: nighttime sleep duration (total number of minutes from sleep onset to sleep offset that were scored as sleep) and sleep efficiency (sleep minutes at night / (sleep minutes at night + wake minutes at night) * 100). The stability of sleep parameters across the five days was moderate to high (α= .79 for nighttime sleep duration, and α= .86 for sleep efficiency). To increase the reliability of estimates, data were averaged across days for each sleep parameter.

The actigraph was usually worn on the non-dominant wrist, but when the child felt uncomfortable, parents were told that the actigraph could be worn on the ankle. Consistent with a previous study in preschoolers (Bélanger et al., 2013), there was no significant location difference for nighttime sleep duration ($t(47) = -1.35$, $p = .19$) or sleep efficiency ($t(47) = 1.37$, $p = .18$). There were no difference in nighttime sleep duration ($t(39) = 0.22$, $p = .83$) or sleep efficiency ($t(39) = 0.31$, $p = .76$) between weekdays and weekends.

Actigraphy data collected could not be analyzed for 17 participants. Data were missing at random for the following reasons: the actigraph was worn but the parent did not complete or return the sleep diary ($n = 2$; 2 TDC), the actigraph was worn but potential artefacts were identified ($n = 1$; 1 TDC), the child refused to wear the actigraph ($n = 11$; 5 mTBI and 6 TDC), co-slept with someone ($n = 2$; 2 mTBI) or was ill ($n = 1$; 1 TDC) throughout the entire data collection.

Statistical Analyses

All data were analyzed using SPSS statistical software (version 24.0; SPSS, Inc., Chicago, IL) and screened for violations of normality. For all analyses, an alpha of .05 was used and effect sizes are reported using Cohen's *d* for continuous data, and Cramer's *V* for categorical data. Available-case analyses were performed to preserve statistical power, given that not all participants completed the actigraphy assessment or that data was missing on various outcome measures (some parents failed to complete the questionnaire booklet or the cognitive assessment could not be completed due to lack of child cooperation).

Group comparisons (mTBI vs. TDC) were conducted on demographic variables (age, sex, SES, ethnicity). Independent sample *t* tests were used for continuous variables, and chi-square tests were conducted for categorical variables. To investigate group differences on executive functions, independent sample *t* tests were performed. Then, a series of multiple hierarchical regressions were performed to assess the interactive effects of children's group (independent variable: mTBI or TDC) and sleep (moderator) on executive functions (outcomes: Delay of Gratification, Conflict Scale). In each equation, group and a sleep measure (CBCL Sleep scale, actigraphy nighttime sleep duration, or actigraphy sleep efficiency) were entered in the first block, followed by their interactive product in the second block. Sleep measures were centered prior to the formation of the interactive term. Then, significant interactions were decomposed following the Preacher, Curran, and Bauer (2006) guidelines.

Results

Final sample

Information on recruitment and follow-up is presented in Figure 1. For both groups, there was no difference in terms of age at recruitment (mTBI: $t(233) = 0.66$, $p = .51$; TDC: $t(110) = 0.44$, $p = .66$) and sex (mTBI: X^2 (1, $N = 238$) = 0.11, $p = .74$; TDC: X^2 (1, $N = 117$) = 2.30, $p = .13$) between those who participated in the study and those who refused. In terms of attrition, there was no difference in terms of age at injury ($t(101) = 0.41$, $p = .68$) and sex (X^2 (1, $N = 238$) = 0.11, $p = .74$) between those who dropped out after recruitment and those who maintained their participation in the mTBI group. In the TDC group, only one participant dropped out, therefore no attrition statistics were computed.

Preliminary analyses

Preliminary analyses of the Shape Stroop data revealed a ceiling effect: 62% of the participants obtained the highest possible score. Therefore, these data were not further considered in the statistical models to prevent bias in the results (Uttl, 2005; Wang, Zhang, McArdle, & Salthouse, 2009).

Main analyses

As shown in Table 2, the two groups did not differ in terms of their age at assessment, sex, socioeconomic status, ethnicity or post-concussive symptoms. In addition, there was no significant difference between the two groups on executive function measures (Delay of Gratification, Conflict Scale) and sleep measures (CBCL Sleep scale, actigraphy nighttime sleep duration and sleep efficiency) 6 months post-injury (see Table 3).

Table 4 presents the bivariate correlations among all continuous variables under study. As expected, CBCL Sleep scale scores were not correlated with actigraphy-derived variables, suggesting that these instruments measure distinct aspects of sleep (Bélanger, Simard, Bernier, & Carrier, 2014). The results of the regression models are displayed in Table 5. The analyses first revealed a significant interaction effect of children's group and CBCL Sleep scale scores on Delay of Gratification ($\beta = -0.15$, $p = .05$). Furthermore, children's group interacted with nighttime sleep duration in the prediction of Conflict Scale ($\beta = 0.38$, $p = .008$). For these two significant interactions, fitted regression lines were plotted at high (+ 1 SD) and low (-1 SD) values of the moderator (CBCL Sleep scale or actigraphy nighttime sleep duration) as depicted in Figure 2. The results revealed a significant group difference for Delay of Gratification performance for children with higher levels of sleep problems on the CBCL ($\beta = -0.77$, $t = -2.24$, $p = .03$), whereas the group difference for children with lower levels of sleep problems was not significant ($\beta = 0.15$, $t = .45$, $p = .66$). Thus, children with mTBI had poorer performance than the TDC group on Delay of Gratification only if they had higher levels of sleep problems. Likewise, post-hoc analyses yielded a significant group difference on Conflict Scale performance for children with shorter nighttime sleep duration ($\beta = -9.31$, $t = 3.02$, $p = .004$), whereas the difference was not significant for children with higher nighttime sleep duration ($\beta = 3.30$, $t = 1.06$, $p = .30$), indicating that children with mTBI exhibited poorer Conflict Scale performance than those in the TDC group only if they had shorter nighttime sleep duration.

To further investigate the relation between sleep and executive functioning, additional analyses were performed in the mTBI group using the pre-injury and 6-month post-injury CBCL Sleep scale, which are intercorrelated ($r = .68$, $p = .001$). There was no significant difference between pre- and post-injury CBCL Sleep scale scores ($t(79) = 0.44$, $p = .66$). Also, both pre-injury and 6-month post-injury CBCL Sleep scale scores significantly predicted Delay of Gratification performance (respectively $\beta = -0.28$, $t = -2.47$, $p = .02$; $\beta = -0.24$, $t = -2.18$, $p = .03$). This suggests that sleep quality, regardless of when it is documented, is important in predicting executive functioning in children with mTBI.

Discussion

The primary goal of the current study was to investigate executive functioning after early mTBI. The performance of preschoolers with mTBI was compared to that of typically developing same-age children. Contrary to our hypothesis, there were no significant group differences on measures of inhibition and cognitive flexibility six months post-injury. These findings differ from previous reports of EF impairments after early TBI, and might be explained by several reasons. First, children in the current study had mild injuries whereas most previous studies have focused on moderate-severe TBI (Ewing-Cobbs et al., 2004; Ganesalingam et al., 2011). Nonetheless, our findings may not merely reflect a general absence of alterations following mild injury, as difficulties in other complex constructs (e.g., social cognition, behaviour, parent-child relations) have previously been identified in the same cohort of children (Bellerose, Bernier, Beaudoin, Gravel, & Beauchamp, 2015, 2017; Gagner, Landry-Roy, Bernier, Gravel, & Beauchamp, 2017;

Lalonde, Bernier, Beaudoin, Gravel, & Beauchamp, 2016). Further, although no EF deficits were identified six months post-injury, we cannot rule out the possibility that children exhibited EF difficulties shortly after the injury, which may have resorbed prior to the six-month timepoint. It is also possible that EF difficulties may subsequently emerge in middle and late childhood. Although EF are rapidly developing during early childhood, such abilities are still immature, even in healthy children. The impact of brain insult on EF may become apparent only later in development when EF become fully functional and mature (e.g., school setting; P. Anderson, 2002; V. Anderson & Catroppa, 2005). One study previously reported EF impairments in attentional control after early mTBI, but children were assessed two years post-injury, which might explain discrepancies with the current results (L. M. Crowe et al., 2013). Further follow-up is required as children mature into middle childhood, especially given that executive abilities have a strong bearing on school success. In addition, this study focused specifically on inhibition and flexibility, but other subdomains of EF may also be relevant in future work.

Early mTBI was not associated with executive deficits or with sleep disturbances six months post-injury. No group differences were found in parental ratings of sleep problems or for actigraphy-derived nighttime sleep duration and sleep efficiency, as previously demonstrated (Landry-Roy et al., 2017). However, the data indicate that a combination of mTBI and poor sleep results in poorer EF outcomes, which supports a "double hazard" effect (Escalona, 1982). Children with mTBI were found to have poorer inhibition and flexibility only if they experienced higher levels of sleep problems (measured by CBCL parental report) or shorter actigraphy nighttime sleep duration. This contributes to explaining our failure to find EF differences at the group level, as EF difficulties post-TBI appear to manifest only among children with sleep disturbances or insufficient sleep. The results align with previous studies in children and adults with TBI, in which high levels of sleep problems reported on sleep questionnaires was associated with poorer EF performance (Mahmood, Rapport, Hanks, & Fichtenberg, 2004; Shay et al., 2014). To our knowledge, this is the first study to depict that sleep disturbances exacerbate EF difficulties in children with mTBI, and through both subjective and objective sleep instruments. This is a promising first step, but independent replication is necessary. Although sleep questionnaires are often criticized for being susceptible to respondent bias (Sadeh, 2015), our results suggest that both subjective and objective measures are likely to be useful in predicting EF post-TBI, and could be used complementarily. The CBCL sleep scale and actigraphy-derived nighttime sleep duration tap into different aspects of sleep, respectively sleep problems and sleep quantity. Therefore, it is perhaps not surprising that they were related to different EF measures.

Of note, regressions performed with sleep efficiency revealed no significant interaction for any of the EF tasks. Therefore, it appears that sleep quantity, regardless of the number of nocturnal awakenings, is more predictive of daytime executive functioning than efficiency *per se*. Our results also indicate that sleep, both pre- and post-injury, is associated with EF after mTBI. This suggests that children with pre-injury sleep problems may be at risk for poorer executive functioning if they sustain a mTBI, and that quality of sleep is important for executive functioning following mTBI in young children.

Two underlying mechanisms are generally proposed to explain the cognitive deficits associated with sleep disturbances. Some theorists argue that sleep disturbances lead to a global decrease in arousal level and alertness, which results in global cognitive impairments, especially on long and simple tasks requiring vigilance (Kjellberg, 1977; Koslowsky & Babkoff, 1992). On the other hand, some argue that sleep disturbances affect specific brain structures and functions (Alhola & Polo-Kantola, 2007). Notably, it has been proposed that sleep disturbances impair cognitive abilities that depend on the prefrontal brain regions, such as EF (Harrison & Horne, 2000; Jones & Harrison, 2001). This theory assumes that performance is impaired on tasks that are subserved by the prefrontal cortex, even if they are interesting and of short duration. Our results are consistent with this latter hypothesis.

The role of sleep in neuroplasticity and neurogenesis has been well established (Benington & Frank, 2003; Kreutzmann, Havekes, Abel, & Meerlo, 2015; Meerlo, Mistlberger, Jacobs, Heller, & McGinty, 2009). It is therefore possible that some aspects of sleep support brain recovery post-TBI. As such, we speculate that poor sleep, whether pre- or post-injury, could impede cognitive recovery post-TBI. In addition, sleep plays an active role in brain maturation throughout development via brain plasticity processes (Sadeh, 2007). The putative impact of sleep is particularly important in the preschool period, which is marked by rapid neural and cognitive development (P. Anderson, 2002; Durston & Casey, 2006). During this developmental period, sleep impairments or brain insult, such as TBI, could possibly increase the risk for cognitive problems. As such, preschoolers who sustain mTBI and present with poor sleep, pre- or post-injury, may be especially at risk for EF difficulties. Finally, it should be kept in mind that other factors (e.g., parental practices, socio-emotional difficulties, fatigue) may account for both sleep disturbances and executive difficulties, and these should be explored in future work (Astill, Van der Heijden, Van Ijzendoorn, & Van Someren, 2012; Byars, Yeomans-Maldonado, & Noll, 2011; Owens, Spirito, & McGuinn, 2000).

Several methodological limitations must be considered when interpreting the current results. First, it is important to acknowledge that regression analyses preclude the establishment of causality between poor sleep and executive functioning. A further limitation of this study is that regression analyses were limited by a modest sample size, which could explain the failure to find certain significant interactions. Also, some participants did not complete all five days of actigraphy data collection. Due to challenges associated with actigraphy compliance, it is not unusual to have fewer than five nights of assessment when working with young children (Bélanger, Bernier, Simard, Desrosiers, & Carrier, 2015; Sazonov, Sazonova, Schuckers, & Neuman, 2004; Scher, Hall, Zaidman-Zait, & Weinberg, 2010; Ward, Gay, Alkon, Anders, & Lee, 2008). However, it would be ideal to exclude children with less than three nights of actigraphy in future replications (Acebo et al., 1999). Besides, we used raw scores for the sleep data, but the use of a normed sleep scale would be helpful in future work to determine the contributions of sleep problems to EF. Finally, we used a typically developing control group to compare children with mTBI to the peers they are likely to interact with and be compared to in everyday life. An injury comparison group could be beneficial to further ensure that the current results represents brain-injury specific effects rather than more general injury effects. We previously showed that the TDC group included in this sample are highly comparable on a very large range of measures to an orthopedic controls group recruited as part of the larger study (M. H. Beauchamp et al., 2017), but sleep variables were not included in those comparisons. Nevertheless, this study improves on previous work through methodological strengths, such as conducting assessments six months post-injury, the use of direct cognitive measures of EF and reliance on both subjective and objective measures of sleep. Although previous studies have investigated EF after pediatric TBI, few have done so in children injured before the age of six years, despite the fact that the young developing brain is particularly vulnerable to such insults and is undergoing major cognitive maturation (L. Crowe et al., 2009; Tsujimoto, 2008).

Conclusions

This study investigated EF and sleep in preschoolers with mTBI, using objective measures of executive functions, a sleep questionnaire and actigraphy data. If replicated, these results would suggest that the presence of a mTBI interacts with sleep in the prediction of executive functioning. This study highlights the importance of documenting sleep in children with TBI, as sleep difficulties place children at risk for later executive dysfunction, which may subsequently impact other spheres of functioning, such as school performance and peer relationships (Asikainen, Kaste, & Sarna, 1996; M. Beauchamp et al., 2011; Nadebaum et al., 2007). Early recognition of sleep disturbances may allow clinicians to intervene in the early course of recovery and potentially reduce the negative impact on EF.

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Table 1

Pre-injury and injury characteristics for the mTBI group

	M (SD)
Age at injury (months)	36.80 (11.54)
Cause of trauma, *n (%)*	
Car accident	2 (2)
Accidental fall	76 (91)
Other non-intentional accidents [a]	6 (7)
Lowest Glasgow coma score, (*n, %)*	13 (4, 5), 14 (6, 7), 15 (74, 88)
Alteration of consciousness, *n (%)*	29 (35)
Neurological symptoms post-mTBI, *n (%)*	
Headaches	31 (37)
Excessive irritability	12 (16)
Persistent vomiting	38 (45)
Hematoma	40 (48)
Drowsiness	48 (57)
Dizziness	11 (13)
Seizure	1 (1)
Blurred vision or hypersensitivity to light	6 (7)
Motor or balance difficulties	10 (12)
Pre-injury CBCL Sleep scale	3.98 (2.91)

Note : [a] Other non-intentional accidents were mainly collision-related (being struck by or against).

Table 2

Participant characteristics

	mTBI *M (SD)*	TDC *M (SD)*	t / X^2	p	d / V
N	84	83			
Age at assessment (months)	43.08 (11.63)	43.19 (11.72)	-.06	.95	.01
Sex [male], *n (%)*	45 (54)	40 (49)	.29	.59	.04
Socioeconomic status index [a]	.01 (.52)	-.02 (.46)	.35	.73	.06
Ethnicity [Caucasian], *n (%)*	65 (84)	64 (83)	.05	.83	.02
Post-concussive symptoms	0.80 (1.49)	0.66 (1.26)	.63	.52	.10

Note : [a] Socioeconomic status index is a standardized composite of parental education and Blishen scores.

Table 3

Group comparisons on executive functions and sleep measures 6 months post-injury

	mTBI		TDC				
Measures	*N*	*M (SD)*	*N*	*M (SD)*	*t*	*p*	*d*
Delay of Gratification	79	4.03 (3.18)	81	4.81 (2.85)	-1.66	.10	.26
Conflict Scale	74	30.15 (16.94)	75	30.87 (16.11)	-.27	.79	.04
CBCL Sleep scale	83	3.70 (2.88)	82	3.13 (2.59)	1.32	.19	.21
Acti. nighttime sleep duration	25	532.60 (48.03)	24	530.42 (48.07)	0.16	.87	.05
Acti. sleep efficiency	25	91.19 (4.37)	24	91.47 (2.41)	-0.27	.79	.08

Table 4

Zero-order correlations among executive functions and sleep measures 6 months post-injury

	2.	3.	4.	5.
1. Conflict Scale	.28**	.01	.29*	.50**
2. Delay of Gratification	-	-.12	-.04	.35*
3. CBCL Sleep scale		-	-.21	-.12
4. Actigraphy nighttime sleep duration			-	.53**
5. Actigraphy sleep efficiency				-

* $p < .05$. ** $p < .01$

Table 5

Summary of regression analyses

	Conflict Scale			Delay of Gratification		
Predictors	Adj. R^2	ΔR^2	β	Adj. R^2	ΔR^2	β
1. Group (A)	-.01	.01	-.02	.01	.02	-.11
CBCL Sleep scale (B)			.02			-.09
2. Interactive Terms (AxB)	-.01	.01	-.12	.03	.02*	-.15*
1. Group (A)	.08	.13	-.20	-.04	.01	-.07
Acti. night. sleep dur. (B)			.31			-.03
2. Interactive Terms (AxB)	.21	.14*	.38*	-.06	.01	.05
1. Group (A)	.23	.27	-.12	.08	.12	-.04
Acti. sleep efficiency (B)			.56*			.49*
2. Interactive Terms (AxB)	.22	.01	-.12	.12	.05	-.27

* $p < .05$.

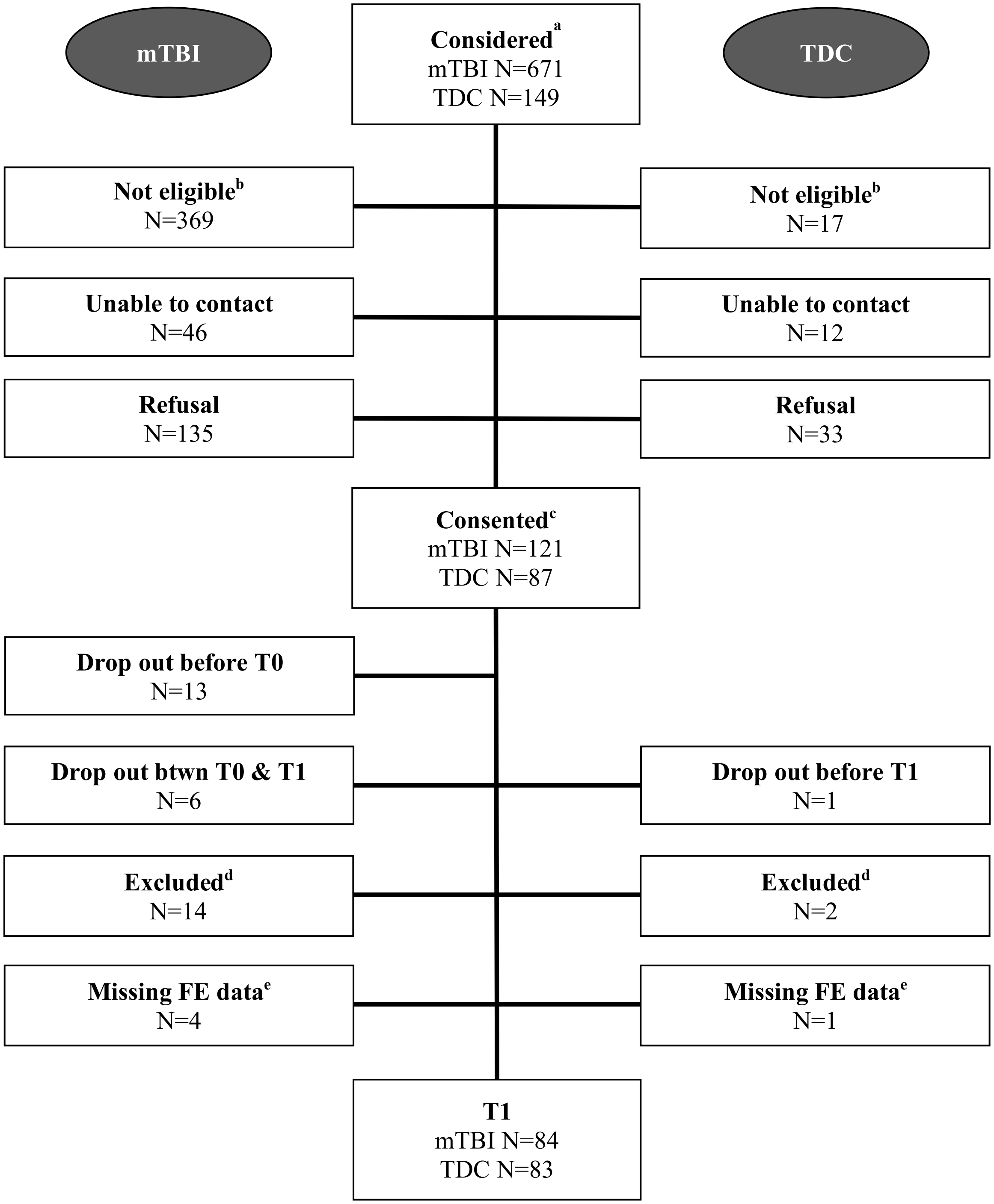
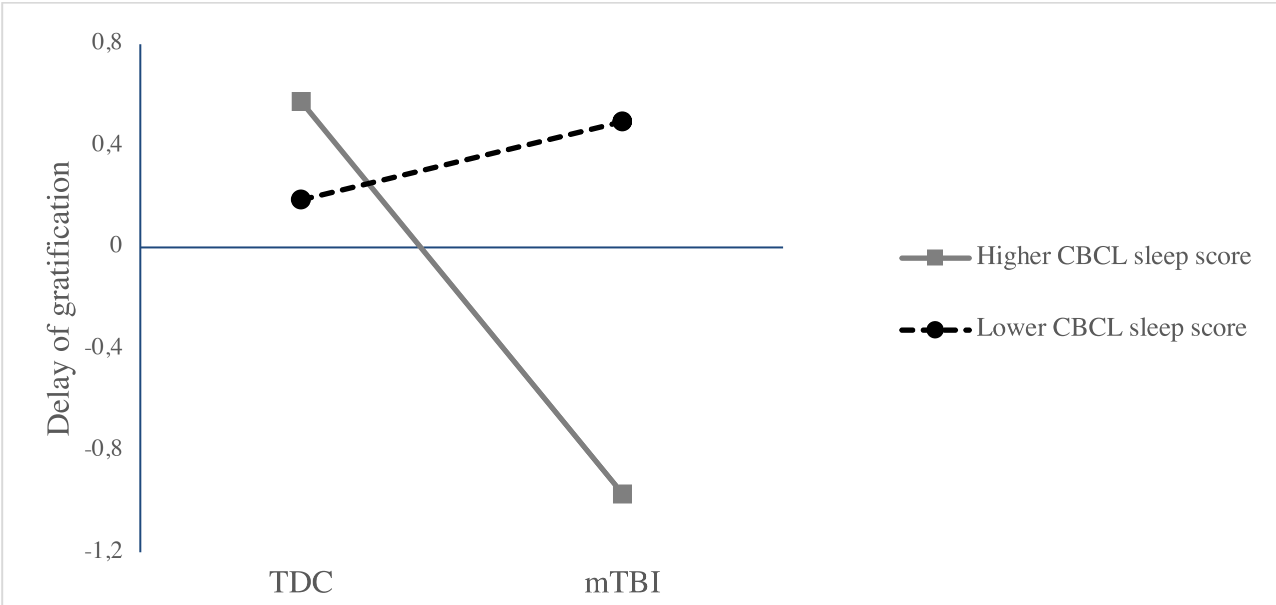
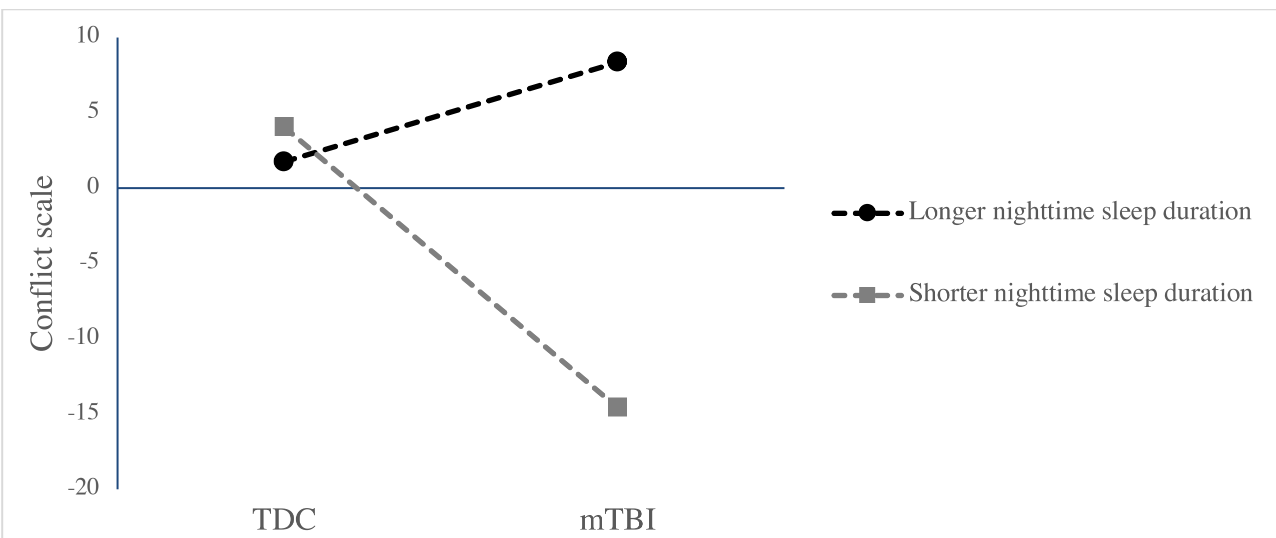


Figure 1. Recruitment and follow-up flowchart. [a] The following emergency department diagnoses were *considered* for participation in the study: *mTBI group:* traumatic brain injury, head fracture, concussion, intracranial bleeding/haemorrhage, polytrauma. TDC participants were *considered* if they received a pamphlet of our study at the local daycare and gave their verbal consent to be contacted by the research coordinator. [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* at T1 because they did not satisfy an inclusion and/or exclusion criterion that had not been detected prior to testing. [e] *Missing FE data* due to failure to complete the evaluation or lack of collaboration.



(a)



(b)

Figure 2. (a) Interactive effects of children's group and CBCL sleep score onto Delay of gratification score. (b) Interactive effects of children's group and actigraphy nighttime sleep duration onto Conflict scale score.

CHAPITRE IV : Discussion générale

Retour sur les objectifs

La survenue d'un traumatisme crânio-cérébral (TCC) durant l'enfance peut entraîner un éventail de conséquences sur le fonctionnement diurne. Qui plus est, un TCC peut bouleverser la vie nocturne de l'enfant. Malgré un nombre croissant d'études sur les perturbations de sommeil consécutives à un TCC pédiatrique, très peu ont ciblé les enfants d'âge préscolaire, soit les enfants âgés de cinq ans et moins. De surcroît, on constate que peu d'études ont mesuré le sommeil objectivement, utilisé des groupes de comparaison et ciblé les blessures les plus légères (Gagner et al., 2015). Ainsi, la présente thèse visait d'abord à évaluer le sommeil des enfants d'âge préscolaire ayant subi un TCC léger (TCCL) entre 18 et 60 mois. Il s'avère particulièrement important d'investiguer le sommeil de ces jeunes enfants étant donné que le sommeil joue un rôle dans le développement et la maturation du cerveau en bas âge. La période préscolaire est notamment marquée par des progrès significatifs au niveau des fonctions exécutives (FE). Or, celles-ci sont vulnérables aux blessures cérébrales, ainsi qu'aux perturbations de sommeil. Le second objectif de cette thèse était d'évaluer le fonctionnement exécutif après un TCCL préscolaire, et d'examiner si celui-ci est modéré par le sommeil post-blessure.

Dans les sections subséquentes, une synthèse des résultats des articles inclus dans cette thèse sera présentée afin d'en abstraire des interprétations. Les forces et limites méthodologiques seront également abordées. Enfin, les avenues de recherche futures et les retombées seront discutées.

Synthèse des résultats

Le premier article de la thèse visait à évaluer l'impact d'un TCCL préscolaire sur le sommeil. Un groupe d'enfants d'âge préscolaire a été recruté, et leur sommeil a été évalué six mois post-TCCL avec des mesures de sommeil à la fois subjective et objective. L'échelle des problèmes de sommeil du *Child Behavior Checklist* a été complétée par un parent. De plus, le sommeil d'un sous-groupe d'enfants a été évalué via le port d'un actigraphe pendant cinq jours. Des enfants ayant subi une blessure orthopédique (BO) et des enfants au développement typique ont aussi été recrutés en guise de groupes de comparaison. Les résultats indiquent que les parents d'enfants ayant subi un TCCL ne rapportent pas plus de problèmes de sommeil chez leur enfant que les parents d'enfants ayant subi une BO et les parents d'enfants au développement typique. De même, les paramètres de sommeil mesurés par l'actigraphe, soit la durée et l'efficacité du sommeil nocturne, sont similaires dans les trois groupes. Cet article a également permis d'explorer les facteurs contribuant au sommeil de l'enfant six mois post-TCCL. D'abord, la présence de difficultés de sommeil pré-morbides, soit avant l'accident, prédit davantage de problèmes de sommeil, ainsi qu'un sommeil nocturne de plus courte durée et de moindre efficacité six mois après la blessure. De plus, une blessure caractérisée par une altération de la conscience, définie comme une perte de conscience ou un état de confusion, prédit un sommeil nocturne de plus courte durée et de moindre efficacité, au-delà des difficultés de sommeil pré-morbides.

Le deuxième article, conduit sur la même cohorte d'enfants, avait pour but d'investiguer le fonctionnement exécutif, et la contribution du sommeil au fonctionnement exécutif post-TCCL. Des tâches directes visant à évaluer les FE ont été administrées six mois post-TCCL. Les enfants ayant subi un TCCL ont obtenu des performances similaires à celles des enfants au développement typique à des épreuves sollicitant l'inhibition et la flexibilité cognitive. Les résultats indiquent que les enfants du groupe TCCL qui présentent des problèmes de sommeil ou un sommeil nocturne de courte durée offrent des performances inférieures aux tâches de FE en comparaison aux enfants au développement typique. Plus précisément, les enfants du groupe TCCL ont obtenu de moins bonnes performances à une épreuve d'inhibition comparativement aux enfants au développement typique s'ils présentaient plus de problèmes de sommeil, tels que rapportés par les parents. Par ailleurs, les enfants ayant subi un TCCL ont obtenu des performances inférieures à celles des enfants au développement typique à une épreuve de flexibilité cognitive si leur sommeil nocturne était de plus courte durée, tel que mesuré par l'actigraphe.

Pistes d'interprétation

Sommeil post-TCC

Considérations méthodologiques. Les résultats du premier article n'ont révélé aucune différence significative entre les trois groupes d'enfants ni au questionnaire standardisé sur les problèmes de sommeil, ni aux variables dérivées de l'actigraphie. L'absence de perturbations de sommeil apparaît plutôt robuste, étant supportée par des mesures à la fois subjective et objective. Comme il s'agit de la première étude à investiguer le sommeil après un TCCL spécifiquement chez l'enfant d'âge préscolaire, il s'avère difficile de comparer les résultats à la littérature existante. Toutefois, ces résultats contrastent avec les conclusions de la revue systématique présentée en annexe de cette thèse (Gagner et al., 2015) et celles d'une revue similaire publiée depuis (Botchway et al., 2018), dans lesquelles la grande majorité des études rapportent des perturbations de sommeil après un TCC pédiatrique (entre 0 et 18 ans). Il est toutefois possible qu'il y ait un certain biais de publication dans la littérature, au détriment des résultats non significatifs. Bien qu'un tel biais ne puisse être exclu, plusieurs aspects méthodologiques méritent aussi d'être considérés dans l'interprétation des résultats.

D'abord, plusieurs études antérieures ont omis d'inclure un *groupe contrôle* (Blinman et al., 2009; Hooper et al., 2004; Korinthenberg et al., 2004; Osorio et al., 2013). Ces études ayant recruté uniquement des enfants ayant subi un TCC vont généralement documenter la proportion d'entre eux qui présentent des difficultés de sommeil, sans offrir de barème de comparaison. Il s'avère toutefois difficile d'interpréter les résultats sachant que les enfants tout-venant peuvent aussi rencontrer des perturbations de sommeil passagères au cours de leur développement (Owens, 2005). Par ailleurs, une blessure traumatique qui n'implique pas la tête (blessure orthopédique; BO) peut aussi perturber le sommeil de l'enfant (Tham et al., 2012). En effet, les symptômes physiques comme la douleur peuvent nuire à l'endormissement ou interrompre le sommeil. L'inclusion d'un groupe d'enfants ayant subi une BO est nécessaire pour déterminer si les difficultés de sommeil sont spécifiquement attribuables à une blessure à la tête, et non à une blessure de manière générale. Dans le premier article, les enfants du groupe TCCL ont été comparés à la fois à des enfants au développement typique et des enfants ayant subi une BO, ce qui permet de conclure à l'absence de perturbations de sommeil post-TCCL avec une plus grande certitude.

Le *niveau de sévérité du TCC* fait également partie des variables à considérer dans l'interprétation des résultats. La littérature dédiée au TCC supporte généralement la notion que les blessures les plus sévères entraînent des atteintes plus importantes, de par une relation dite « dose-réponse » entre le niveau de sévérité et l'étendue des conséquences. De fait, les perturbations de sommeil sont généralement plus prononcées chez les enfants ayant subi un TCC modéré ou sévère (Beebe et al., 2007; Shay et al., 2014; Tham et al., 2012). Pour cette raison, des difficultés aussi prononcées n'étaient pas attendues au sein du groupe TCCL recruté dans la présente thèse. Néanmoins, les évidences suggèrent qu'un TCCL peut aussi bouleverser significativement le sommeil. En effet, il a été démontré que les enfants ayant subi un TCCL présentent davantage de perturbations de sommeil après la blessure comparativement à des enfants sans blessure (Pillar et al., 2003; Tham et al., 2012; Theadom et al., 2016). Ainsi, il importe de considérer d'autres facteurs pour une meilleure compréhension des perturbations de sommeil spécifiquement après un TCCL.

Entre autres, le *temps écoulé depuis la blessure* est une variable déterminante. Plusieurs des études ayant rapporté des difficultés de sommeil après un TCCL (Blinman et al., 2009; Hooper et al., 2004; Korinthenberg et al., 2004) ont ciblé la phase aiguë, soit les quelques semaines suivant l'accident. Ces résultats ne sont pas surprenants étant donné que les symptômes post-commotionnels sont généralement plus prononcés en phase aiguë (Yeates et al., 2009; Zemek et al., 2016). Il n'est pas exclu que la cohorte d'enfants recrutés dans la présente étude ait présenté des perturbations de sommeil peu de temps après la blessure, mais que celles-ci se soient résorbées pour la majorité d'entre eux dans les mois suivants, et n'étaient donc plus apparentes six mois après la blessure. D'autres études ont pourtant démontré la persistance de problèmes de sommeil plusieurs mois et années après un TCCL pédiatrique (Kaufman et al., 2001; Milroy et al., 2008). Toutefois, les difficultés à long terme sont possiblement plus subtiles ou plus rares, de sorte qu'elles sont plus difficiles à déceler. Certaines études ont d'ailleurs recruté spécifiquement des participants avec des plaintes de sommeil. Par exemple, Kaufman et ses collègues (2001) ont recruté des participants âgés entre 10 et 16 ans qui rapportaient des difficultés de sommeil plus de trois ans après avoir subi un TCCL. De fait, leurs plaintes subjectives étaient corroborées par des enregistrements polysomnographiques et actigraphiques démontrant un sommeil de moindre efficacité en comparaison avec un groupe contrôle. Il est à noter que la présence de difficultés de sommeil n'était pas un critère d'inclusion dans la présente thèse, ce qui contraste avec les études ayant utilisé un tel critère pour documenter des difficultés de sommeil au long cours. Rappelons toutefois que les résultats du premier article ont permis d'identifier certains enfants plus enclins à présenter des perturbations de sommeil, lesquelles pourraient possiblement perdurer à plus long terme. En effet, la présence de difficultés de sommeil pré-morbides et d'une altération de la conscience après l'impact traumatique nuisent au sommeil mesuré six mois post-TCCL.

Considérations théoriques. Compte tenu que les résultats de la présente étude contrastent avec la plupart des études antérieures chez les enfants plus âgés et les adolescents, on peut émettre l'hypothèse que l'impact d'un TCCL sur le sommeil serait moindre chez le jeune enfant. Cette proposition va toutefois à l'encontre de la théorie de la vulnérabilité, voulant que le cerveau immature ou en cours de maturation soit plus vulnérable à une blessure cérébrale (Anderson et al., 2005). Cette notion de vulnérabilité est souvent évoquée dans le domaine du TCC préscolaire et est bien supportée par plusieurs études empiriques ayant démontré qu'un TCC en bas âge affecte le fonctionnement diurne de l'enfant (Anderson et al., 2005; Beauchamp & Anderson, 2013). Or, des facteurs *intrinsèques* et *extrinsèques* propres à l'enfant d'âge préscolaire pourraient jouer un rôle protecteur en ce qui a trait au fonctionnement nocturne.

D'abord, les fonctions cognitives sont encore immatures chez l'enfant d'âge préscolaire. Sa perception et compréhension de la blessure traumatique est plus limitée, et par le fait même, on peut s'attendre à des réactions différentes à celles des enfants plus âgés et des adolescents. Les réactions cognitives, comportementales et émotionnelles au TCCL sont bien décrites dans le modèle de Hou et al. (2012) consacré aux adultes. D'abord, les réactions cognitives font référence aux croyances, perceptions et pensées. Par exemple, le fait d'entretenir des perceptions négatives envers le TCCL ou d'anticiper des symptômes comme des difficultés de sommeil peut nuire au rétablissement. Ensuite, les réactions comportementales reflètent en quelque sorte le style d'adaptation, et peuvent s'exprimer notamment par l'évitement d'une situation (ne pas aller au lit par crainte de ne pas dormir) ou des réponses inadéquates (aller au lit trop tôt ou trop longtemps). Enfin, les réactions émotionnelles, comme l'anxiété et la dépression, occupent une place importante et non négligeable dans le maintien des symptômes. Un TCCL peut être vécu en tant que tel comme un événement potentiellement stressant, de même que l'expérience médicale (examens et traitements) qui en découle. L'individu qui a subi un TCCL peut aussi vivre de l'anxiété en lien avec les possibles conséquences de la blessure sur son fonctionnement. Selon Hou et al. (2012), l'ensemble de ces réactions suite à la blessure sont déterminantes dans la persistance des symptômes post-commotionnels. Bien que ce modèle soit destiné aux adultes, il pourrait aussi s'appliquer aux enfants d'âge scolaire et adolescents. Par exemple, l'enfant peut s'inquiéter des répercussions de sa blessure sur ses résultats académiques, ses activités sociales, etc. Qui plus est, une telle blessure peut bousculer sa vie quotidienne et amener divers changements (p. ex. routines, pratique d'activités sportives et récréatives). Des difficultés à s'adapter à ces changements peuvent mener à une détresse émotionnelle chez certains enfants. Les symptômes internalisés, comme l'anxiété ou la dépression, sont connus pour nuire au sommeil. En retour, les perturbations de sommeil peuvent entretenir ces symptômes. Ce chevauchement entre le sommeil et la santé psychologique a d'ailleurs été démontré dans plusieurs études auprès d'enfants en bonne santé (Chorney, Detweiler, Morris, & Kuhn, 2007; Gregory & Eley, 2005; Williams, Berthelsen, Walker, & Nicholson, 2017).

Or, des fonctions cognitives bien développées sont requises pour interpréter les possibles conséquences d'un TCCL et y réagir. L'enfant plus âgé ou l'adolescent peut présenter des réactions cognitives, comportementales et émotionnelles similaires à l'adulte telles que décrites dans le modèle de Hou et al. (2012). En revanche, il est moins probable qu'un enfant d'âge préscolaire, qui détient de moindres capacités de mentalisation, puisse développer des problèmes de sommeil en lien avec des biais cognitifs, des comportements mal adaptés ou des ruminations. Il n'est cependant pas exclu que l'enfant puisse présenter des symptômes internalisés. De fait, les résultats d’une étude antérieure auprès de la même cohorte d’enfants que celle de la présente thèse révèlent que les enfants ayant subi un TCCL présentent davantage de comportements internalisés que les enfants des groupes contrôles six mois après la blessure (Gagner et al., 2017). Ainsi, le sommeil des enfants inclus dans cette étude apparaît préservé, en dépit de comportements internalisés.

Une autre particularité du TCC préscolaire concerne l’environnement dans lequel le jeune enfant se rétablit. Dans les premières années de vie, l’enfant est particulièrement perméable à l’influence de ses parents, avec lesquels il interagit quotidiennement. Au fil du développement, les milieux où gravite l’enfant se diversifient et les opportunités d’interactions sociales se multiplient. En effet, lorsque les enfants débutent l’école vers l’âge de cinq ans, ils passent de plus en plus de temps avec les intervenants scolaires, et plus tard à l’adolescence avec leurs pairs. Ainsi, la présence accrue des parents dans la vie quotidienne du jeune enfant est une caractéristique distinctive du TCC préscolaire. Beauchamp et al. (2020) ont proposé le modèle PARENT (*Perception, Attribution, and Response after Early Non-inflicted Traumatic Brain Injury*) pour décrire le rôle du facteur « parent » suite à un TCCL préscolaire. D’après leur modèle, les habiletés du parent à *percevoir, attribuer* et *répondre* aux symptômes post-commotionnels de son enfant donnent le ton à la direction et au rythme du rétablissement. D’abord, le parent doit percevoir des symptômes ou changements dans le comportement de son enfant après la blessure. Ensuite, il doit pouvoir interpréter et attribuer ces symptômes à la blessure. Enfin, il doit répondre de façon appropriée et ajustée à ceux-ci.

Prenons par exemple un enfant qui développe des difficultés de sommeil à titre de symptôme post-commotionnel. Son parent doit d’abord bien détecter ce changement. Les parents vigilants et sensibles aux besoins et à l’état de leur enfant y parviennent généralement plus facilement. Le parent qui met en lien ces difficultés avec la blessure va pouvoir ajuster ses soins et interventions auprès de son enfant. Selon le profil des difficultés de sommeil, le parent peut mettre en place différentes stratégies. Par exemple, le parent peut ajuster l'horaire de sommeil ou ajouter des périodes de repos (siestes). Le parent peut également intervenir auprès de l'enfant qui présente des difficultés d'endormissement. Les routines de coucher, l'aménagement d'une chambre propice au sommeil et le réconfort physique peuvent faciliter l'endormissement. Le parent peut ainsi donner le ton à la récupération après un TCCL préscolaire et possiblement permettre un rétablissement plus rapide en encourageant une quantité suffisante de sommeil de bonne qualité. Il est donc possible que les difficultés se résorbent plus rapidement et ne persistent pas dans les six mois post-blessure. Les stratégies mentionnées ne sont pas exclusives au jeune enfant, mais s'appliquent plus facilement en bas âge étant donné le rôle central qu'occupent les parents dans la vie quotidienne de l'enfant. Habituellement, les parents surveillent de près le sommeil de leur enfant dans les premières années de vie. De plus, ils instaurent généralement un horaire de sommeil régulier compte tenu des besoins de sommeil plus importants en bas âge. En contrepartie, il s'avère plus difficile pour un parent de réguler le sommeil de son adolescent.

Le parent est bien évidemment un acteur important dans le développement de son enfant (Bornstein, 2019). D'après Beauchamp et al. (2020), son rôle est d'autant plus important en bas âge lorsque des perturbations développementales surviennent comme un TCCL. Les jeunes enfants détiennent des capacités verbales et introspectives plus limitées qui affectent leur capacité à comprendre et exprimer leurs difficultés. Après un TCCL préscolaire, la détection des symptômes post-commotionnels repose en grande partie sur les parents. Par exemple, il est peu probable que l'enfant se plaigne spontanément de difficultés de sommeil. De plus, les symptômes peuvent être plus difficiles à détecter et interpréter. En ce qui a trait aux perturbations de sommeil, celles-ci peuvent être subtiles et prendre diverses formes chez le jeune enfant, incluant des comportements externalisés. Par exemple, un enfant qui présente des difficultés de sommeil peut se montrer plus irritable ou impulsif. Pour reprendre le modèle PARENT de Beauchamp et al. (2020), les habiletés parentales sont sollicitées pour bien *détecter* les comportements d'irritabilité ou d'impulsivité et les *attribuer* à des difficultés de sommeil sous-jacentes. Certains parents pourraient attribuer l'irritabilité ou l'impulsivité erronément à de l'opposition, de sorte que leur *réponse* serait différente et inadéquate. Après un TCC, les difficultés de sommeil sont variables, allant de l'insomnie à l'hypersomnolence, ce qui nécessite d'autant plus que le parent fasse une bonne lecture de son enfant pour répondre adéquatement.

Beauchamp et collègues (2020) soulignent aussi l'importance de considérer plusieurs caractéristiques parentales qui influencent le processus *perception-attribution-réponse.* Parmi celles-ci, l'état psychologique du parent est déterminant. La survenue d'un TCC peut engendrer une variété d'émotions chez le parent. Le plus souvent, les parents rapportent des inquiétudes quant au rétablissement de leur enfant, du stress relié à leur rôle de parent suite à la blessure, une augmentation de la charge parentale ressentie ainsi qu'une détresse psychologique (Brown et al., 2013; Clark et al., 2008; Taylor et al., 2001). Bien qu'à un moindre niveau, des plaintes similaires sont aussi documentées suite aux formes plus légères de TCC (Ganesalingam et al., 2008; Hawley et al., 2003). Ces émotions négatives (stress élevé, dépression, culpabilité) peuvent altérer ou entraver les capacités du parent à percevoir, attribuer et répondre adéquatement aux symptômes de leur enfant. Le contexte culturel et familial dans lequel les symptômes se manifestent doit aussi être considéré. La description des perturbations de sommeil est très subjective, car elle dépend de l'interprétation, des attentes, de la tolérance et des valeurs personnelles des parents (Sadeh & Anders, 1993). Comme la perception d'un sommeil perturbé diffère d'un parent à l'autre, l'attribution et la réponse présentent inévitablement des variations. On observe toutefois que les perturbations de sommeil sont le plus souvent identifiées lorsque le parent trouve que son propre sommeil est perturbé ou que ses activités nocturnes sont affectées (Turnbull et al., 2013). En somme, le sommeil de l'enfant devrait être conceptualisé dans le contexte familial. La présente thèse s'est intéressée spécifiquement au sommeil de l'enfant, mais les études futures gagneraient à s'intéresser davantage aux parents.

Fonctionnement exécutif post-TCC

La thèse visait aussi à investiguer l'impact d'un TCCL préscolaire sur les fonctions cognitives de haut niveau, soit les FE. Les résultats du deuxième article n'indiquent aucune différence significative entre les enfants ayant subi un TCCL et ceux ayant subi une BO aux tâches d'inhibition et de flexibilité cognitive administrées six mois après la blessure. À notre connaissance, aucune étude ne s'est attardée précédemment au fonctionnement exécutif après un TCC préscolaire spécifiquement dans sa forme légère. Il s'avère ainsi difficile de comparer directement les résultats obtenus avec ceux des études antérieures ayant ciblé le TCC préscolaire modéré ou sévère (Ewing-Cobbs et al., 2004; Ganesalingam et al., 2011). De fait, des difficultés exécutives sont plus fréquentes et plus graves après les blessures les plus sévères, autant chez les enfants d'âge préscolaire que les enfants plus âgés (Levin & Hanten, 2005). Néanmoins, les résultats du deuxième article s'ajoutent à ceux des études réalisées auprès d'enfants d'âge scolaire ayant subi un TCCL et dont les performances exécutives sont sensiblement similaires à celles d'enfants contrôle (Babikian & Asarnow, 2009; Babikian et al., 2011; Maillard-Wermelinger et al., 2009). À la lumière de ces résultats, il apparaît peu probable qu'un TCCL occasionne des dommages aux réseaux exécutifs suffisants pour altérer de façon permanente le fonctionnement exécutif.

Bien qu'aucune difficulté exécutive n'ait été relevée six mois après la blessure, il n'est pas exclu que des faiblesses exécutives étaient présentes dans la phase aiguë, mais que celles-ci se soient résorbées à six mois post-TCCL, comme pour les perturbations de sommeil. Il est également possible que des difficultés exécutives émergent plus tard. À mesure que l'enfant grandit, les exigences environnementales, académiques, comportementales et cognitives augmentent, de sorte que le système exécutif est de plus en plus sollicité. En lien avec cette proposition, on constate que plusieurs études sur le TCC préscolaire ont évalué le fonctionnement exécutif plusieurs années après la blessure, ce qui contraste avec l'évaluation réalisée six mois post-TCCL dans la présente thèse. Par exemple, Crowe et al. (2013) ont montré que des enfants ayant subi un TCCL avant l'âge de trois ans performaient moins bien à une mesure de contrôle inhibitoire administrée plus de deux ans après la blessure, comparativement à des enfants au développement typique. Il demeure toutefois impossible de déterminer si ces difficultés étaient présentes plus tôt dans la phase de récupération ou si elles ont émergé au fil du temps. Rappelons que les différentes composantes exécutives suivent des trajectoires développementales distinctes et émergent à différents stades du développement, conjointement à la maturation du cerveau (Anderson, 2002). La période préscolaire représente une période dynamique et charnière où se produisent des progrès importants au niveau exécutif, particulièrement pour les composantes fondamentales (p. ex. inhibition, flexibilité). Les fonctions plus complexes (p. ex. planification, résolution de problèmes) émergent plus tard dans le développement et se construisent à partir des fonctions plus simples. Ainsi, des déficits pourraient éventuellement devenir apparents au niveau des fonctions plus complexes si la séquence prédéterminée du développement cérébral a été perturbée par une blessure en bas âge. En somme, pour statuer sur l'impact d'un TCCL à l'âge préscolaire sur le fonctionnement exécutif, un suivi longitudinal (en phase aiguë et post-aiguë) apparait primordial au fil de la maturation des FE et de l'augmentation des exigences. Un tel suivi est particulièrement important pour les enfants qui subissent une blessure en bas âge, étant donné l'immaturité de leurs habiletés cognitives au moment de la blessure.

Il est également possible que les outils disponibles pour évaluer les FE du jeune enfant ne permettent pas de détecter des difficultés, d'autant plus si celles-ci sont subtiles. En effet, les tâches directes qui ont été utilisées dans ce projet sont plutôt brèves, mais il est possible que des difficultés se manifestent si l'effort cognitif devait être soutenu sur une plus longue période. Toutefois, l'absence de différence relevée dans le deuxième article ne semble pas être l'unique reflet d'un manque de sensibilité des tâches. À l'appui, elles se sont avérées efficaces pour détecter des difficultés chez d'autres populations cliniques infantiles. Par exemple, des déficits ont été documentés à la tâche *Conflict Scale* chez des enfants prématurés (Miller, DeBoer, & Scharf, 2018) et des enfants qui présentent un trouble du spectre de l'autisme (Faja & Dawson, 2014).

Rappelons que certaines études ont rapporté des difficultés exécutives après un TCCL pédiatrique. Or, on constate que plusieurs de ces études n'ont pas utilisé des tâches directes, mais se sont plutôt appuyées sur des inventaires comportementaux complétés par les parents pour évaluer le fonctionnement exécutif des enfants. Parmi ceux-ci, le *Behavior Rating Inventory of Executive Function* (BRIEF; Gioia et al., 2000) est le plus connu et a d'ailleurs été utilisé auprès d'enfants ayant subi un TCC à l'âge préscolaire (Crowe et al., 2013; Keenan et al., 2018) ou plus tard dans leur développement (Maloney, Schmidt, Hanten, & Levin, 2020; Sesma et al., 2008). Le BRIEF a été conçu pour évaluer facilement et à faible coût les comportements reflétant les FE de l'enfant dans son environnement quotidien. Toutefois, les tâches directes et le BRIEF ne doivent pas être utilisés de façon équivalente ou interchangeable comme mesures exécutives. Au niveau de la validité concomitante, il a été démontré à maintes reprises que les scores obtenus au BRIEF ne corrèlent pas, ou très peu, avec les performances de l'enfant aux tâches directes présumées mesurer le même construit (Anderson, Anderson, Northam, Jacobs, & Mikiewicz, 2002; Conklin, Salorio, & Slomine, 2008; Gross, Deling, Wozniak, & Boys, 2015; McAuley, Chen, Goos, Schachar, & Crosbie, 2010; Nordvall, Jonsson, & Neely, 2017; Shuster & Toplak, 2009). Par ailleurs, la validité prédictive des tâches directes apparaît supérieure à celle des inventaires comportementaux pour prédire le fonctionnement scolaire, lequel dépend fortement des habiletés exécutives (Gerst, Cirino, Fletcher, & Yoshida, 2017; Soto et al., 2020). À la lumière de ces résultats, les tâches directes et le BRIEF semblent mesurer des construits distincts.

Bien que les échelles comme le BRIEF permettent d'évaluer le comportement des enfants au quotidien, les comportements capturés ne semblent pas être liés spécifiquement aux processus exécutifs sous-jacents (Soto et al., 2020). Selon Toplak, West, et Stanovich (2013), les tâches directes permettraient d'évaluer l'efficacité des processus exécutifs dans un environnement structuré avec peu de distracteurs, alors que les inventaires comportementaux comme le BRIEF permettraient de décrire la capacité de l'enfant à atteindre un objectif dans des conditions non structurées. D'après Spiegel, Lonigan, et Phillips (2017), le BRIEF refléterait les capacités d'autorégulation, et serait étroitement lié aux comportements externalisés. De la sorte, le BRIEF est conceptualisé par plusieurs auteurs comme un indicateur général du comportement de l'enfant dans diverses situations. Il s'apparenterait ainsi à d'autres questionnaires destinés à documenter le comportement de l'enfant, comme le *Child Behavior Checklist* (CBCL). Celui-ci a d'ailleurs été utilisé dans sa version complète auprès de la même cohorte d'enfants que celle de la présente thèse. Les résultats révèlent que les mères d'enfants ayant subi un TCCL rapportent davantage de comportements internalisés et externalisés chez leur enfant six mois après la blessure que les mères d'enfants ayant subi une BO et les mères d'enfants au développement typique (Gagner et al., 2017).

Selon la prémisse que le BRIEF est, un indicateur du comportement, des différences de groupe auraient possiblement pu être observées, comme au CBCL, si le BRIEF avait été utilisé dans la présente thèse. Comme aucune différence de groupe n'a été relevée aux tâches directes administrées six mois post-TCCL, les changements comportementaux rapportés par Gagner et al. (2017) ne semblent pas sous-tendus par des difficultés exécutives.

Sommeil et fonctions exécutives

Cette thèse a aussi permis d'investiguer la contribution du sommeil au fonctionnement exécutif après un TCCL préscolaire. Les résultats indiquent que les enfants ayant subi un TCCL et qui présentent des problèmes de sommeil ou un sommeil de courte durée offrent des performances inférieures aux tâches de FE en comparaison aux enfants au développement typique. Ces résultats s'ajoutent aux études longitudinales, corrélationnelles et expérimentales auprès de différentes populations et groupes d'âge ayant déjà démontré l'importance du sommeil pour le fonctionnement cognitif, particulièrement pour les fonctions de haut niveau (Sadeh, 2007). Cette relation entre le sommeil et les FE n'est cependant pas exclusive aux enfants ayant subi un TCCL, mais s'applique aussi aux enfants au développement typique. En effet, des corrélations significatives entre les mesures de sommeil et les mesures de FE ont été observées dans tout l'échantillon. Or, cette relation apparaît d'autant plus prononcée chez les enfants ayant subi un TCCL. Même si le design méthodologique ne permet pas de faire des inférences causales, la survenue d'un TCCL, auquel s'ajoutent des perturbations de sommeil, tend à exposer l'enfant à des difficultés exécutives accrues six mois post-TCCL.

Ces résultats renforcent l'idée d'adopter une perspective multifactorielle dans la compréhension clinique du TCCL. Dans les deux dernières décennies, de nombreuses études se sont intéressées aux facteurs qui permettent de prédire le fonctionnement de l'enfant post-TCC.

Les facteurs les plus communément cités sont les facteurs pré-morbides (p. ex. caractéristiques de l'enfant et de sa famille), les facteurs liés à la blessure (p. ex. sévérité et localisation de la blessure), les facteurs développementaux (p. ex. âge au moment de la blessure), les facteurs environnementaux (p. ex. statut socio-économique, pratiques parentales) et les facteurs génétiques (p. ex. ApoE; Anderson & Catroppa, 2006; Catroppa, Anderson, Beauchamp, & Yeates, 2016). Pour décrire les interactions complexes entre ces multiples facteurs, plusieurs modèles théoriques ont été proposés dans la littérature sur le TCC pédiatrique (Beauchamp & Anderson, 2013; Dennis, Yeates, Taylor, & Fletcher, 2007; Yeates et al., 2009). Par exemple, le modèle multidimensionnel de Beauchamp et Anderson (2013) met en relation plusieurs variables susceptibles d'influencer le fonctionnement de l'enfant à différents stades de la récupération post-TCC. On y retrouve d'abord les facteurs pré-blessures inhérents à l'enfant et son environnement familial avant la survenue du TCC. Ensuite, la récupération dépend inévitablement des caractéristiques de la blessure, comme la localisation et la sévérité. Les facteurs post-blessures comme le fonctionnement cognitif de l'enfant suite à l'accident et la qualité de l'environnement sont d'autres variables susceptibles d'influencer la récupération.

Les résultats de la thèse sont compatibles avec le modèle de Beauchamp et Anderson (2013). En effet, les résultats du premier article mettent en lumière la contribution de facteurs pré-blessures (historique de difficultés de sommeil) et caractéristiques de la blessure (altération de la conscience) pour prédire le sommeil post-TCCL. Par ailleurs, le deuxième article illustre la notion d'interaction entre le fonctionnement de l'enfant post-TCCL (c.-à-d. son fonctionnement nocturne) et ses habiletés cognitives (c.-à-d. fonctions exécutives). En bref, il apparaît important de tenir compte des interactions complexes entre de multiples facteurs pour prédire le rétablissement et le fonctionnement de l'enfant après la blessure. Plus l'enfant présente de facteurs de risque, plus il est susceptible de présenter des atteintes. Les études futures pourraient inclure d'autres variables (p. ex. relations parent-enfant, statut socioéconomique) susceptibles d'affecter le sommeil et le fonctionnement exécutif pour dresser un portrait plus complet.

Cette compréhension multifactorielle est aussi pertinente pour expliquer la variabilité dans le rétablissement d'un enfant à l'autre. Chaque enfant présente des facteurs de risque et facteurs de protection qui lui sont propres et susceptibles d'interagir les uns avec les autres à différents stades de la récupération post-TCCL. Les résultats de la thèse ont permis d'identifier certains enfants plus vulnérables, un phénomène connu sous le terme de « *miserable minority* » (Rohling, Larrabee, & Millis, 2012; Wood, 2004). Toutefois, il importe de rappeler que la majorité des enfants qui subissent un TCCL se rétablissent bien, avec peu ou pas de conséquences. Dans la littérature sur le TCC, les études se concentrent généralement sur les conséquences adverses et l'identification des facteurs susceptible de nuire au rétablissement. Ces études sont essentielles pour comprendre l'impact d'un TCC sur le fonctionnement de l'enfant, et identifier les enfants les plus à risque pour une prise en charge rapide. Toutefois, les résultats de la thèse rappellent qu'il ne faut pas perdre de vue que la majorité des enfants ont un rétablissement favorable. De fait, les analyses réalisées à l'échelle du groupe n'ont montré aucune différence significative aux mesures de sommeil et de FE. On retrouve d'ailleurs de plus en plus d'études dans la littérature qui rapportent des résultats favorables et mettent en lumière la résilience des enfants (Beauchamp et al., 2019; Durish, Yeates, & Brooks, 2019). Dans les études futures, les modèles prédictifs gagneraient à investiguer davantage les facteurs protecteurs, en complément aux facteurs de risque (Beauchamp & Yeates, 2019).

Forces et limites

Les articles inclus dans cette thèse présentent des forces qui méritent d'être soulignées. Une première force, qui a d'ailleurs été soulevée dans une récente revue systématique de Botchway et al. (2018), est l'utilisation d'une mesure de sommeil objective, en complémentarité avec une mesure subjective. Il s'agit de la première cohorte d'enfants d'âge préscolaire ayant subi un TCC dont le sommeil est évalué objectivement, et ce, via le port d'un actigraphe. Bien que l'actigraphie a été réalisée seulement chez un sous-groupe d'enfants, cette thèse a permis de faire la démonstration qu'il est tout à fait possible d'utiliser l'actigraphie auprès de cette population. Une autre force réside dans l'utilisation d'une mesure de sommeil pré-blessure chez les enfants blessés (TCCL et BO). Celle-ci a été obtenue en demandant aux parents de l'enfant de remplir un questionnaire après la survenue de la blessure et d'y répondre en fonction du sommeil de leur enfant avant l'accident. Cette mesure est toutefois imparfaite puisqu'elle est susceptible d'être biaisée par la perception du répondant, dont le souvenir peut être altéré. Néanmoins, elle apparaît assez valide puisqu'elle permet de prédire à la fois les variables de sommeil dérivées de l'actigraphie et les problèmes de sommeil rapportés par les parents six mois post-TCCL. Enfin, soulignons que le fonctionnement exécutif a été évalué avec des tâches directes, spécialement conçues et adaptées pour les enfants d'âge préscolaire.

En ce qui a trait aux limites, il convient de préciser que l'échantillon recruté était plutôt homogène et composé d'une population urbaine majoritairement caucasienne et à faible risque socioéconomique. Or, le sommeil est non seulement dicté par des processus biologiques, mais est aussi influencé par plusieurs facteurs environnementaux. En ce sens, plusieurs études ont montré des variations culturelles, que ce soit au niveau de l'horaire de sommeil, des habitudes de co-sommeil, de la durée et qualité du sommeil (Buckhalt, El-Sheikh, & Keller, 2007; Crosby, LeBourgeois, & Harsh, 2005; Durrence & Lichstein, 2006; Giannotti & Cortesi, 2009). Celles-ci peuvent être mise en lien avec différentes pratiques et valeurs culturelles. Or, la race et l'ethnicité sont inévitablement associées au statut socioéconomique, lequel pourrait expliquer les variations culturelles. Par exemple, les enfants qui vivent dans de plus petits foyers peuvent être forcés de partager une chambre ou un lit. Il apparaît donc difficile de généraliser les résultats de la thèse à des populations qui proviennent d'autres cultures ou milieux.

Plusieurs limites relatives aux instruments de sommeil méritent aussi d'être soulignées. Bien qu'il s'agisse d'une mesure objective, l'actigraphie est une mesure indirecte du sommeil et comporte un certain risque d'erreur. Elle se base sur les mouvements de l'enfant pour inférer les périodes de sommeil et d'éveil. Les algorithmes parviennent généralement à bien détecter le sommeil, mais ils détectent moins bien les périodes d'éveils (Sadeh, 2011; Sitnick et al., 2008). Néanmoins, la validité des données est supérieure lorsque l'actigraphe et l'algorithme sont appropriés à l'âge des enfants (Bélanger et al., 2013). De plus, l'utilisation d'un agenda de sommeil complémentaire permet de limiter les artefacts de mouvement (Meltzer, Montgomery-Downs, et al., 2012; Sadeh & Acebo, 2002). Bien que le risque d'erreur ait été minimisé dans la présente thèse, il demeure important d'être bien informé des limites de l'actigraphie et de rappeler qu'il s'agit d'une mesure indirecte, et non une évaluation directe de l'activité neurophysiologique, comme le permet la polysomnographie. Par ailleurs, rappelons que les analyses ont ciblé uniquement des variables nocturnes, soit la durée et l'efficacité du sommeil nocturne. Bien que l'actigraphe enregistrait l'activité motrice sur une période continue de 24 heures, aucune variable diurne n'a été rapportée dans la présente thèse. En effet, la validité des données diurnes étaient compromises pour plusieurs enfants dont l'agenda de sommeil n'avait pas été complété durant la journée par le parent ou l'éducatrice.

Le questionnaire *Child Behavior Checklist* (CBCL) présente également des limites. Rappelons que les données de la présente thèse s'inscrivent dans une étude plus large qui visait à caractériser les conséquences d'un TCCL à l'âge préscolaire. Le CBCL a été complété par les parents dans l'objectif premier de documenter les comportements de l'enfant (Achenbach & Rescorla, 2001). Pour la présente sous-étude ciblant plus spécifiquement le sommeil, l'échelle des problèmes de sommeil du CBCL, composée de sept items, a été utilisée. Toutefois, il serait intéressant dans des études ultérieures d'inclure un questionnaire standardisé conçu spécialement pour évaluer le sommeil et qui contient un plus grand nombre d'items, comme par exemple le *Child's Sleep Habits Questionnaire* (Owens et al., 2000). Qui plus est, le CBCL été complété par un seul parent, généralement la mère. Bien qu'il existe forcément des disparités entre les réponses des deux parents, les résultats d'une étude de Bélanger et al. (2014) indiquent néanmoins une bonne correspondance entre les réponses du père et de la mère d'enfants d'âge préscolaire en bonne santé à l'échelle des problèmes de sommeil du CBCL ($r = .57$). Le CBCL demeure malgré tout une mesure subjective, qui peut introduire des sources de biais liés aux perceptions, attentes et préoccupations du parent répondant. Il serait intéressant d'ajouter un deuxième répondant dans les études futures, et de comparer les perceptions des pères et des mères. Étant donné que les conséquences du TCCL peuvent être difficiles à détecter et passer inaperçues aux yeux d'un parent, il serait d'autant plus pertinent de documenter la perception des deux parents.

Enfin, il importe d'évoquer les groupes de comparaison. Dans le premier article, les enfants ayant subi un TCCL ont été comparés à un groupe d'enfants ayant subi une BO ainsi qu'à un groupe d'enfants au développement typique. Les enfants ayant subi un BO présentent l'avantage d'avoir vécu une expérience médicale similaire aux enfants du groupe TCCL (p. ex. présentation aux services d'urgence, stress, examens radiologiques, prise de médicament; Yeates, 2010). Ils permettent également de contrôler pour les caractéristiques pré-morbides (p. ex. difficultés comportementales, problèmes attentionnels) et sociodémographiques (p. ex. statut socioéconomique, pratiques parentales) qui sont associés au risque de subir une blessure traumatique (Goldstrohm & Arffa, 2005; Lalloo & Sheiham, 2003; McKinlay, Kyonka, et al., 2010; Winqvist, Jokelainen, Luukinen, & Hillbom, 2007). De leur côté, les enfants au développement typique offrent la possibilité de comparer les enfants ayant subi un TCCL avec leurs pairs qu'ils côtoient au quotidien à la garderie et dans les milieux récréatifs ou communautaires. Le présent projet est l'un des rares à avoir recruté ces deux groupes de comparaison, alors que la majorité des études optent pour un seul des deux groupes. En contrepartie, seuls les enfants au développement typique ont été utilisés comme groupe de comparaison dans le deuxième article. Les enfants ayant subi une BO n'ont pu être inclus dans les analyses étant donné que peu d'entre eux détenaient des données actigraphiques. Le recrutement d'enfants ayant subi une BO fut malheureusement moindre qu'attendu, et plusieurs ont été recrutés et évalués avant l'acquisition des actigraphes. Cette décision d'inclure uniquement les enfants au développement typique dans le deuxième article est supportée par les résultats de l'article présenté en annexe de la thèse qui a démontré l'absence de différences significatives entre les deux groupes contrôles (Beauchamp, Landry-Roy, Gravel, Beaudoin, & Bernier, 2017). En effet, les résultats de cet article n'indiquent aucune différence entre les enfants ayant subi une BO et les enfants au développement typique sur une panoplie de variables démographiques, développementales, médicales, familiales, comportementales, adaptatives et cognitives.

Avenues futures

En dépit des défis méthodologiques, la présente thèse a permis de démontrer la faisabilité d'utiliser l'actigraphie chez de jeunes enfants ayant subi un TCCL, et pourra inciter d'autres groupes de recherche à l’utiliser. La durée et l’efficacité du sommeil nocturne ont été utilisées dans les analyses, mais il serait intéressant d’explorer dans de futures études d’autres variables actigraphiques comme la latence d’endormissement, le temps passé au lit, la durée des éveils après l’endormissement ou encore la durée des siestes. En effet, il est possible que les enfants puissent compenser le manque de sommeil nocturne par des siestes étant donné que celles-ci sont déjà fréquentes en bas âge. Qui plus est, rappelons que les parents sont très impliqués dans la vie des jeunes enfants et peuvent établir un horaire de sieste plus régulier pour favoriser le rétablissement post-TCC.

Les recherches futures devraient aussi s’intéresser davantage aux parents. À la lumière des résultats du premier article, le sommeil de l’enfant apparaît préservé après un TCCL préscolaire, possiblement en raison de facteurs intrinsèques et extrinsèques uniques. En revanche, des perturbations de sommeil pourraient émerger chez son parent, qui lui porte le fardeau du TCCL et s’occupe quotidiennement de l’enfant blessé. De fait, les parents dont l’enfant a subi un TCC, même léger, peuvent présenter un niveau de stress élevé et des éléments de détresse psychologique après la blessure (Hawley et al., 2003), ce qui peut interférer avec leur sommeil.

Par ailleurs, la présente thèse s’est centrée sur les marqueurs de sommeil. Or, la revue systématique présentée en annexe a permis de constater que les symptômes de fatigue sont également fréquents après un TCC pédiatrique (Gagner et al., 2015). Bien que la fatigue accompagne habituellement les perturbations de sommeil post-TCC, elle peut aussi se manifester indépendamment de difficultés de sommeil (Wilkinson et al., 2018). Ainsi, la fatigue après un TCCL préscolaire demeure à investiguer, de même que sa relation avec la cognition. En effet, les difficultés de sommeil ou un sommeil insuffisant peuvent contribuer à la fatigue, qui pourrait à son tour nuire au fonctionnement exécutif étant donné que l'utilisation des FE est très énergivore comparativement à d'autres fonctions cognitives (p. ex. langage).

Par ailleurs, les études futures devraient aussi chercher à élucider les corrélats neurologiques sous-jacents aux perturbations de sommeil post-TCCL, ainsi que la relation avec l'altération de conscience qui a été identifiée comme un prédicteur significatif dans le deuxième article. La formation réticulée, qui s'étend sur toute la hauteur du tronc cérébral, est une région d'intérêt puisqu'elle est impliquée à la fois dans les mécanismes d'éveil et l'état de conscience. Récemment, une série d'études s'est intéressée à son rôle dans les perturbations de sommeil post-TCC. La tractographie par tenseur de diffusion (DTT) a permis de mettre en évidence chez des adultes ayant subi un TCC des lésions au niveau de la formation réticulée, plus précisément dans les voies dorsales et ventrales qui projettent sur les noyaux du thalamus et de l'hypothalamus (Jang, Kim, & Kwon, 2018; Jang, Kim, & Lee, 2019; Jang & Kwon, 2016). Qui plus est, ces lésions étaient associées aux plaintes de fatigue et d'hypersomnie rapportées par les patients post-TCC. Subséquemment, Jang et ses collaborateurs (2019) ont investigué la relation avec la perte de conscience. En effet, une dysfonction transitoire ou une blessure de la formation réticulée peut aussi perturber l'état de conscience. Ils ont démontré que la perturbation de l'état de conscience était associée à des lésions axonales plus importantes de la formation réticulée, et pourrait être donc être utilisée comme indicateur de la sévérité de la blessure. Les auteurs soulignent que le tronc cérébral est particulièrement vulnérable aux forces cinétiques d'accélération et décélération lors du TCC, lesquelles pourraient perturber à la fois l'état de conscience et les mécanismes d'éveil/sommeil. D'autres études sont nécessaires pour comprendre les liens de causalité entre les perturbations de sommeil, l'altération de la conscience et les lésions axonales au niveau du tronc cérébral. Il apparaît également important de rappeler que les mécanismes d'éveil et de l'état de conscience sont régulés par un réseau complexe de structures, et les études ne devraient pas se limiter à la formation réticulée, bien qu'il s'agisse d'une piste intéressante.

En ce qui a trait aux FE, un nombre limité de tâches a été inclus dans la présente thèse. Bien que la période préscolaire soit décisive pour l'acquisition des FE, les tests validés et destinés aux enfants d'âge préscolaire sont peu nombreux. Par le biais d'un suivi longitudinal, il serait possible d'administrer un plus large éventail de tests exécutifs lorsque les enfants seront plus âgés. Un tel suivi permettrait aussi d'étudier l'impact à long terme d'un TCCL préscolaire à la fois sur les FE élémentaires et les FE plus complexes.

Outre le fonctionnement exécutif, il serait intéressant dans de futures études d'investiguer l'impact du sommeil sur d'autres aspects du fonctionnement post-TCCL. Plusieurs études auprès d'enfants au développement typique ont démontré que les perturbations de sommeil sont associées à des difficultés comportementales (Astill et al., 2012; Lavigne et al., 1999). Or, de telles difficultés sont fréquemment documentées après un TCC et ont également été observées auprès de la cohorte d'enfants présentée dans cette thèse. En effet, il a été démontré que les enfants ayant subi un TCCL préscolaire présentent davantage de comportements intériorisés et extériorisés que les enfants ayant subi une BO et les enfants au développement typique (Gagner et al., 2019; Gagner et al., 2017). Il serait ainsi intéressant d'investiguer si des perturbations de sommeil après la blessure nuisent à d'autres aspects du fonctionnement de l'enfant, notamment au plan comportemental.

Implications

L'actigraphie a connu un essor dans la recherche sur le sommeil au cours des dernières années. Cette technique d'évaluation du sommeil n'est cependant pas exclusive aux laboratoires de recherche et il est souhaitable d'encourager son utilisation dans les milieux cliniques. Lorsqu'un enfant présente des perturbations de sommeil persistantes post-TCC, un actigraphe pourrait être proposé par le clinicien. Une inspection visuelle des tracées actigraphiques est accessible à tous et fournit de riches informations sur le profil de sommeil de l'enfant. Avec une courte formation, il est aisé de faire une analyse plus approfondie des données. Même si les parents sont bien placés pour décrire les habitudes de sommeil de leur enfant, ils ne sont pas toujours au courant des comportements de l'enfant durant la nuit et leur perception est aussi teintée d'une certaine subjectivité. L'utilisation ponctuelle d'un actigraphe auprès de certains enfants s'avère un outil additionnel pour aider les cliniciens à raffiner leurs conclusions cliniques. Au besoin, des interventions adaptées aux difficultés de sommeil rencontrées par l'enfant peuvent être proposées.

À ce jour, les interventions répertoriées dans la littérature qui ciblent les difficultés de sommeil post-TCC s'adressent aux adultes. Dans une récente revue systématique, Bogdanov, Naismith, et Lah (2017) ont recensé dix études ayant évalué des interventions pour les difficultés de sommeil post-TCC. Toutefois, aucune des études recensées ne s'adressait à la population pédiatrique. Il serait pertinent d'adapter ces interventions aux enfants, d'évaluer si les stratégies pour les enfants tout-venant ou les enfants avec certaines conditions neurodéveloppementales (p. ex. trouble du spectre de l'autisme, déficit de l'attention/hyperactivité) peuvent être utilisées, ou de développer des interventions spécialement destinées aux enfants ayant subi un TCC. Habituellement, les difficultés de sommeil chez le jeune enfant sont traitées par des thérapies de type comportemental, plutôt que par des traitements pharmacologiques (Mindell, Kuhn, Lewin, Meltzer, & Sadeh, 2006). De plus, des conseils d'hygiène de sommeil, c.-à-d. des recommandations ciblant les habitudes de vie, l'environnement ou la routine de sommeil, sont également bénéfiques (Mindell, Meltzer, Carskadon, & Chervin, 2009). À titre d'exemple, il est recommandé aux parents d'offrir une chambre propice au sommeil (sombre, fraîche, tranquille et confortable), d'adopter une routine au coucher, de garder un horaire de sommeil régulier (la semaine et la fin de semaine) et de limiter l'activité physique et l'utilisation de technologie stimulante en fin de soirée. Il est essentiel que les enfants qui présentent des perturbations de sommeil post-TCC puissent recevoir une attention clinique afin de favoriser un rétablissement plus rapide, et s'assurer que les perturbations de sommeil n'ont pas d'autres répercussions à long terme, comme par exemple au niveau du fonctionnement exécutif.

Plus largement, cette thèse soulève l'importance du sommeil pour la santé et le développement de tous les enfants, pas seulement ceux qui ont subi un TCC. Il est bien reconnu que l'activité physique et l'alimentation sont essentielles au maintien d'une bonne santé globale. Ces deux thèmes ont d'ailleurs été le sujet de maintes campagnes de sensibilisation dans les médias, et sont fréquemment promus dans divers établissements (p. ex. écoles, milieux de garde, cliniques médicales). Or, le sommeil est tout aussi important, mais plus souvent négligé. Sans aucun doute, le sommeil est un thème qui occupe beaucoup de place dans la vie des parents et qui anime bien des discussions. Son rôle dans le développement est toutefois méconnu et il apparaît essentiel de déployer des efforts pour éduquer le grand public au sujet de l'importance du sommeil.

Les professionnels de la santé devraient aussi être mieux renseignés sur les perturbations et troubles de sommeil durant l'enfance, particulièrement les neuropsychologues pédiatriques. Une évaluation neuropsychologique est indiquée lorsqu'un enfant rencontre diverses difficultés cognitives. Or, les résultats de la thèse rappellent l'importance de considérer l'impact potentiel de difficultés de sommeil concomitantes sur les habiletés cognitives au sein du tableau clinique. Durant l'entrevue clinique, le neuropsychologue devrait interroger les parents sur les habitudes de sommeil, la durée et la qualité du sommeil de l'enfant. Les neuropsychologues devraient aussi être outillées pour faire de l'éducation sur le sommeil, renseigner les parents sur les bonnes habitudes de sommeil à adopter et proposer des recommandations.

Conclusion

Cette thèse s'inscrit dans le souci de mieux comprendre l'impact d'un TCCL chez les enfants d'âge préscolaire. Plusieurs changements cérébraux s'opèrent pendant la période préscolaire et le jeune enfant réalise des progrès considérables. Pour un développement optimal, l'enfant a besoin de conditions favorables, incluant un bon sommeil. Les résultats de la thèse démontrent que des perturbations de sommeil après un TCCL préscolaire exposent l'enfant à des difficultés exécutives accrues. Une telle altération du fonctionnement exécutif n'est pas souhaitable étant donné que les FE sont impliquées dans plusieurs sphères, que ce soit pour les habiletés sociales, la régulation émotionnelle ou les apprentissages. Il apparaît ainsi essentiel d'évaluer et surveiller le sommeil après un TCCL en bas âge.

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ANNEXES

ANNEXE A : Article 3

Sleep-Wake Disturbances and Fatigue after Pediatric Traumatic Brain Injury: A Systematic Review of the Literature

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Abstract

Sleep-wake disturbances (SWD) after traumatic brain injury (TBI) are frequently reported and can persist several years post-injury. The adult literature covering this topic is exhaustive; numerous robust studies using objective measures of sleep and advanced methodologies support the presence of SWD post-TBI. Despite being the leading cause of morbidity in children and adolescents, however, relatively few studies exist investigating SWD and symptoms of fatigue after pediatric TBI. We undertook a systematic search of the literature in PsycINFO, MEDLINE, CINAHL, and Web of Science databases with the aim of documenting persistent fatigue and SWD after pediatric TBI. Terms and keywords pertaining to TBI, children/adolescents, and sleep/fatigue were used, and of the 461 articles initially identified, 24 studies met our inclusion criteria. According to the results of the literature search, SWD and fatigue are common after pediatric TBI. The methodologies used in the studies reported varied widely, however, and were mainly subjective (e.g., questionnaires and interviews with caregivers). Moreover, no study targeted preschool children despite the fact that there is evidence regarding the critical importance of sleep for appropriate cognitive development, especially in high-order cognitive functioning. In sum, the results of the studies analyzed were consistent with the presence of SWD and fatigue after pediatric TBI, but there is a lack of information concerning this relationship in younger children. The use of more objective measures, such as actigraphy, could bring better insight to the impact of TBI on the quality of children's sleep.

Keywords : childhood; fatigue; sleep; systematic review; traumatic brain injury.

Introduction

Traumatic brain injury (TBI) in children and adolescents is a significant cause of disability and mortality. Pediatric TBI can cause serious disruptions to cognitive (e.g., memory problems, attentional deficits), behavioral (e.g., aggressive behavior, conduct problems), social (e.g., lack of empathy, social isolation), and emotional functions (e.g., anxiety, irritability; Anderson & Catroppa, 2007; Andrews, Rose, & Johnson, 1998; Ayalon, Borodkin, Dishon, Kanety, & Dagan, 2007; Beauchamp, Dooley, & Anderson, 2010; Beauchamp & Anderson, 2010; Castriotta et al., 2007; Li & Liu, 2013; Verma, Anand, & Verma, 2007; Yeates et al., 2009). There is also increasing appreciation of the presence of sleep-wake disturbances (SWD) after pediatric TBI, with disturbed sleep reported as one of the most frequent post-injury symptoms, even after mild TBI (Hooper et al., 2004). Fatigue has also been described as a common and persistent symptom of pediatric TBI. It can accompany SWD or be observed as an isolated symptom (Limond, Dorris, & McMillan, 2009).

Both post-traumatic SWD and fatigue can compromise the rehabilitation process and return to activities (Ouellet & Morin, 2006). They can also seriously impact performance in multiple cognitive, social, and functional domains. Given their detrimental effect on everyday functioning and on cognitive development, it is crucial to assess sleep and fatigue in young survivors of TBI.

SWD are defined as changes in nighttime sleep resulting in daytime impairments (Page, Berger, & Johnson, 2006). Post-traumatic SWD may manifest themselves in several ways during the post-injury recuperation and rehabilitation period. Studies in the adult population demonstrate that SWD are extremely prevalent in the acute post-injury phase (Haboubi, Long, Koshy, & Ward, 2001; Rao et al., 2008), but can also persist for several years thereafter (Kempf, Werth, Kaiser, Bassetti, & Baumann, 2010). Serious conditions such as sleep-related breathing disorders, sleep-related movement disorders, and circadian rhythm sleep disorders have all been documented after adult TBI (Ayalon et al., 2007; Castriotta et al., 2007; Verma et al., 2007). More common complaints include insomnia, hypersomnia, and excessive daytime sleepiness (Ouellet, Beaulieu-Bonneau, & Morin, 2006; Rao & Rollings, 2002).

The DSM-V defines insomnia as a difficulty initiating sleep, trouble maintaining sleep, or early-morning awakening with inability to return to sleep (American Psychiatric Association, 2013). Conversely, hypersomnia is characterized by an increased amount of sleep. Hypersomnia and excessive daytime sleepiness are often used interchangeably. Excessive daytime sleepiness, however, does not refer to an increased amount of sleep, but rather an increased propensity for daytime sleep and an inability to stay awake (Overeem & Reading, 2010).

Adults with TBI may also complain of an increased need to sleep, regardless of excessive daytime sleepiness. To account for these differences, Sommerauer and colleagues (2013) introduced the term "post-traumatic pleiosomnia". Excessive daytime sleepiness and increased sleep need are especially common among adults who sustain TBI. It is also recognized that fatigue is burdensome to patients with TBI and may result in important functional limitation (Cantor et al., 2008; Sigurdardottir, Andelic, Roe, & Schanke, 2009). Fatigue, however, should not be confused with excessive daytime sleepiness (Limond et al., 2009).

Fatigue can be defined in different ways, because it is essentially a subjective experience. It is a multidimensional construct, involving both mental and somatic components, and generally characterized by difficulty initiating voluntary activities and a sustained feeling of exhaustion and exertion, but it does not include signs of excessive sleepiness (Chaudhuri & Behan, 2004). It has been documented as one of the most persistent symptoms of TBI and is present even after mild injuries (Ponsford & Sinclair, 2014). Many studies suggest that fatigue symptoms impede the recovery process (Belmont, Agar, Hugeron, Gallais, & Azouvi, 2006). The etiology of post-TBI fatigue is complex and is likely to be related to numerous factors such as brain damage, endocrine disorders, medication use, pain, and psychological distress (Belmont et al., 2006; Mollayeva et al., 2013; Zgaljardic et al., 2014).

SWD and fatigue in children who sustain TBI are not as well documented as in adults. This is a serious concern given that adequate sleep is of paramount importance for cognitive, behavioural, and socioemotional functioning during childhood and adolescence (Bernier, Carlson, Bordeleau, & Carrier, 2010; Räikkönen et al., 2010; Vaughn, Elmore-Staton, Shin, & El-Sheikh, 2015). In healthy children, SWD have been associated with a range of difficulties. Disruption in the quality and duration of sleep can impact academic performance (Dewald, Meijer, Oort, Kerkhof, & Bogels, 2010; El-Sheikh, Buckhalt, Mark Cummings, & Keller, 2007). SWD in childhood have also been related to both externalizing and internalizing behavior problems (Astill, Van der Heijden, Van Ijzendoorn, & Van Someren, 2012; Lavigne et al., 1999). Other studies suggest that sleep problems may contribute to anxiety and depression in childhood and adolescence (Chorney, Detweiler, Morris, & Kuhn, 2008; Shanahan, Copeland, Angold, Bondy, & Costello, 2014).

Thus, it appears particularly critical to determine whether SWD and excessive fatigue are present after pediatric TBI, because children and adolescents who sustain brain injuries are already at risk for cognitive, behavioural, and socioemotional difficulties (Li & Liu, 2013), and these are likely to be exacerbated by poor quality sleep. In addition, TBI can have a negative impact on families more globally, because parents of children with sleep pathology experience increased stress levels (Moore, Gordon, & McLean, 2012). These findings highlight the importance of investigating sleep quality in children who sustain TBI.

In sum, there is growing empirical support for SWD and fatigue after pediatric TBI, and such problems can influence the development and quality of life of children and their families. To gain a better understanding of the relationship between sleep and brain injury in children and adolescents, we undertook a systematic review of the literature covering persistent SWD and fatigue after pediatric TBI.

The main goal of this review was to investigate the presence of SWD and fatigue as persistent symptoms after pediatric TBI–that is, symptoms that last beyond the acute rehabilitation period. We expected that the literature would report SWD and fatigue as common symptoms in the chronic phase after pediatric TBI. A subgoal was to describe the various methodologies used to assess children's sleep and fatigue.

Method

Search strategy

We performed a systematic search of the four following psychology and medicine databases: Medline (Ovid MEDLINE(R) In-Process & Other Non-Indexed Citations and Ovid MEDLINE(R)), PsycINFO (Ovid), CINAHL (Plus with Full Text), and Web of Science (Core Collection). The search strategy was designed to combine three groups of key terms pertaining to TBI, the pediatric population, and sleep/fatigue issues. Appropriate truncations and possible misspellings were included.

The keywords for the search were : "(brain injur* or head injur* or concussion* or TBI or head trauma or brain trauma) AND (sleep disorder* or sleep* problem* or sleep* disturbance* or insomnia or sleep apnea or sleepwalk* or hypersomnia or sleep deprivation or somnolence or narcolepsy or parasomnia* or sleep wake or circadian rhythms or fatigue or tiredness) AND (child* or pediatric or infant* or toddler* or preschooler* or school child* or youth or teenager* or adolescen* or school-age)". The fields of search were adapted for each database as follows:

- Ovid search (Medline and PsycINFO): Identifiers (ID), Heading Word (HW), Title (TI)
- CINAHL search: Word in Subject Heading (MW)
- Web of science search: topic

Eligibility criteria

Inclusion criteria. All articles in which the main purpose of the study was to report SWD and/or fatigue as outcomes of pediatric TBI were retrieved according to the following criteria:

1. Articles that reported original data from pediatric TBI and SWD and/or fatigue as outcomes after a TBI
2. Accidental or intentional closed TBI
3. Participants aged between 0 and 18 years old at the time of the injury
4. Assessment of fatigue and/or sleep conducted with subjective (e.g., questionnaires) and/or objective (e.g., polysomnography or actigraphy) measures
5. Articles published before 2015 (the last search was conducted in January 2015).

Exclusion criteria. We rejected all articles that contained at least one of the following exclusion criteria:

1. Study population included only adults or included children or adolescents, but their results were not reported separately, precluding any possible conclusions specific to pediatric TBI
2. Penetrating head injury or information concerning type of TBI not specified
3. No direct measure of SWD or fatigue (e.g., review of the literature)

4. SWD and/or fatigue assessed exclusively during the acute post-injury phase (e.g., on-field symptoms after sport concussion)
5. SWD and/or fatigue reported during hospitalisation (e.g., sleep problems in the intensive care unit)
6. Conference proceedings, books, book chapters
7. References that did not provide complete information allowing retrieval of the document (e.g., missing journal name, volume, issue number and pages)
8. Articles in languages other than English or French.

Study selection

In the first stage of screening, two reviewers (CG, FL) independently performed a preliminary screening of titles and abstracts to exclude any article that did not meet the inclusion and exclusion criteria. In the second stage of screening, all remaining articles were read in full for closer inspection. When the article met the selection criteria, it was added to the current systematic review. Disagreements about eligibility were resolved through consensus.

Data collection process

Data for the final article selection were extracted by one reviewer into a structured database previously designed to ensure recollection of a maximum of pertinent information. The relevant information was classified under each of the following headings: title, authors, year, study design, sample size, TBI severity, age at injury or assessment, type of control group (when applicable), assessment of sleep and/or fatigue, time since TBI, main results related to SWD and/or fatigue, and limitations.

Risk of bias

The quality of retained studies was independently assessed by two reviewers (CG, CL-R) based on a minor adaptation of the criteria proposed by Hayden and associates (2006). The following risks of bias were evaluated: study participation (e.g., there is adequate participation in the study by eligible individuals), study attrition (e.g., response rate is adequate), outcome measurement (e.g., the method and setting of measurement are the same for all study participants), confounding measurement and account (e.g., important potential confounders are accounted for in the study design), and analysis (e.g., there is no selective reporting of results). Presence of bias was judged either as "Yes," "Partly," "No," or "Unsure."

Results

Study selection

Details of the search results are presented in Figure 1. The initial search identified 461 articles based on the keywords and search criteria used in the four databases. A total of 130 articles were found in Ovid (Medline and PsycINFO), 72 in CINAHL, and 259 in Web of Science. After removal of 71 duplicates, 390 were screened to evaluate whether inclusion/exclusion criteria were met. After the first stage of screening (review of titles and abstracts), 294 articles were excluded. After the second stage of screening (full-text review), 72 were excluded, for a final total of 24 articles included in this systematic review. Of note, the majority of articles were rejected because they did not meet inclusion criteria 3 (pediatric population).

Table 1 summarizes the articles that were included for systematic review as a function of participant characteristics, assessment of sleep and/or fatigue, time since injury, main results related to SWD, and main results related to fatigue. Publication dates ranged from 1986 to 2014, and only seven articles were published in the last 5 years (Aaro Jonsson, Emanuelson, & Charlotte Smedler, 2014; Falk, 2013; Osorio et al., 2013; Schneider, Emery, Kang, Schneider, & Meeuwisse, 2010; Shay et al., 2014; Sumpter, Dorris, Kelly, & McMillan, 2013; Tham et al., 2012).

Study characteristics

Several studies evaluated fatigue and/or sleep as part of a wider range of symptoms (e.g., headaches, dizziness). For purposes of this review, however, only SWD and fatigue are reported here, even if they were not the primary outcome of the study.

Five articles consisted of case studies (Busek & Faber, 2000; Dhondt, Verhelst, Pevernagie, Slap, & Van Coster, 2009; Drake, 1986; Nagtegaal, Kerkhof, Smits, Swart, & van der Meer, 1997; Patten & Lauderdale, 1992), nine consisted of retrospective cohort studies (Aaro Jonsson et al., 2014; Kaufman et al., 2001; Milroy, Dorris, & McMillan, 2008; Nacajauskaite, Endziniene, Jureniene, & Schrader, 2006; Necajauskaite, Endziniene, & Jureniene, 2005; Osorio et al., 2013; Overweg-Plandsoen et al., 1999; Pillar et al., 2003; Sumpter et al., 2013), and the remaining were prospective cohort studies (Beebe et al., 2007; Blinman, Houseknecht, Snyder, Wiebe, & Nance, 2009; Falk, 2013; Hilger & Bagłaj, 2009; Hooper et al., 2004; Korinthenberg, Schreck, Weser, & Lehmkuhl, 2004; Ponsford et al., 1999; Schneider et al., 2010; Shay et al., 2014; Tham et al., 2012). Excluding case studies, total sample sizes ranged from 21 (Aaro Jonsson et al., 2014) to 4193 (Schneider et al., 2010) participants. Twelve articles of 24 included a control group, which was either composed of typically developing children (TDC; Kaufman et al., 2001; Pillar et al., 2003; Schneider et al., 2010), children with orthopedic injuries (OI; Beebe et al., 2007; Milroy et al., 2008; Nacajauskaite et al., 2006; Necajauskaite et al., 2005; Overweg-Plandsoen et al., 1999; Ponsford et al., 1999; Shay et al., 2014; Tham et al., 2012) or siblings (Sumpter et al., 2013). Twelve articles did not use any control groups and, therefore, it is not possible in these works to know whether the fatigue and SWD reported are specifically attributable to the brain injury (5 of these 12 articles were case studies; Busek & Faber, 2000; Dhondt et al., 2009; Drake, 1986; Nagtegaal et al., 1997; Patten & Lauderdale, 1992).

Timing of sleep and/or fatigue assessment ranged from 1 week (Ponsford et al., 1999) to 13 years (Aaro Jonsson et al., 2014) post-TBI. Two studies included a baseline assessment in the acute phase post-TBI (Blinman et al., 2009; Korinthenberg et al., 2004), but the results of these assessments were not considered in the current review because the aim was to document fatigue and SWD as persistent symptoms of TBI. Only four studies reported retrospective ratings of pre-injury sleep and/or fatigue (Beebe et al., 2007; Shay et al., 2014; Sumpter, Dorris, Kelly, & McMillan, 2014; Tham et al., 2012). Of note, Necajauskaite and coworkers (2005) and Ponsford and colleagues (1999) included more global pre-injury measures such as the presence of a health condition or neurological/psychiatric problems before the injury. It is unclear, however, whether they specifically assessed pre-injury sleep and/or fatigue and if so, results pertaining to those variables were not reported in the article.

TBI severity varied across the different articles. Twelve studies involved only children who had sustained mild TBI (Blinman et al., 2009; Dhondt et al., 2009; Hilger & Bagłaj, 2009; Kaufman et al., 2001; Korinthenberg et al., 2004; Milroy et al., 2008; Nacajauskaite et al., 2006; Necajauskaite et al., 2005; Overweg-Plandsoen et al., 1999; Pillar et al., 2003; Ponsford et al., 1999; Schneider et al., 2010), 1 involved children with mild to moderate TBI (Falk, 2013), 3 involved only moderate to severe TBI,(Beebe et al., 2007; Busek & Faber, 2000; Sumpter et al., 2013) 2 involved only severe TBI (Drake, 1986; Patten & Lauderdale, 1992), 5 involved all levels of severity (Aaro Jonsson et al., 2014; Hooper et al., 2004; Osorio et al., 2013; Shay et al., 2014; Tham et al., 2012), and 1 case study (Nagtegaal et al., 1997) did not report TBI severity.

Of the 24 articles, 17 used only subjective measures of sleep and/or fatigue (Aaro Jonsson et al., 2014; Beebe et al., 2007; Blinman et al., 2009; Falk, 2013; Hilger & Bagłaj, 2009; Hooper et al., 2004; Korinthenberg et al., 2004; Nacajauskaite et al., 2006; Necajauskaite et al., 2005; Osorio et al., 2013; Overweg-Plandsoen et al., 1999; Patten & Lauderdale, 1992; Pillar et al., 2003; Ponsford et al., 1999; Schneider et al., 2010; Shay et al., 2014; Tham et al., 2012), 4 only objective measures (Busek & Faber, 2000; Dhondt et al., 2009; Drake, 1986; Nagtegaal et al., 1997), and 3 used a combination of both subjective and objective measures (Kaufman et al., 2001; Milroy et al., 2008; Sumpter et al., 2013).

All studies except two (Nacajauskaite et al., 2006; Necajauskaite et al., 2005) reported either fatigue or SWD after TBI. The two studies reporting no difference between TBI and control groups were based on the same sample population and written by the same author group. Moreover, one study (Beebe et al., 2007) found that children who sustained a moderate TBI displayed a small decline in SWD from pre- to post-injury, whereas children who sustained a severe TBI displayed increased post-injury sleep problems. Articles comprising multiple time points for assessing SWD or fatigue generally showed a decrease in symptoms over time.

Risk of bias

Table 2 describes the quality assessment performed according to the five potential risks of bias. Overall, seven studies (Hilger & Bagłaj, 2009; Nacajauskaite et al., 2006; Nagtegaal et al., 1997; Necajauskaite et al., 2005; Overweg-Plandsoen et al., 1999; Pillar et al., 2003; Tham et al., 2012) comprised at least one risk of potential bias. More precisely, one study (Drake, 1986) presented a potential risk of bias related to "study participation". It consisted of a case study, and key characteristics of the patient were unspecified (e.g., sociodemographic characteristics, preexisting medical condition). Three studies (Hilger & Bagłaj, 2009; Nacajauskaite et al., 2006; Necajauskaite et al., 2005) had shortcomings related to "study attrition".

Of note, the two studies that did not report any SWD after TBI included this type of methodological weakness. For example, in the study by Nacajauskaite and associates (2006), the response rate was relatively low (57% in the TBI group and 55% in the control group), and the authors did not specify the reasons for this low rate and did not provide detailed specifications on whether key characteristics differed between participants who accepted to participate and those who did not.

Finally, three studies (Overweg-Plandsoen et al., 1999; Pillar et al., 2003; Tham et al., 2012) had potential risks of bias related to "outcome measurement". Pillar and coworkers (2003), for example, used a homemade questionnaire to assess the outcome variables of interest, and there appears to be no information provided on the validation or psychometric properties of this questionnaire. Moreover, the evaluation environment was not the same for all study participants because the control group completed the questionnaire at school, but the TBI group did not.

Discussion

This systematic review aimed to investigate the presence of persistent SWD and fatigue as outcomes of pediatric TBI and, as a subgoal, to address the methodologies used to assess these problems. Despite the variety of methods used to evaluate sleep throughout the studies reviewed, all 24 studies except two (Nacajauskaite et al., 2006; Necajauskaite et al., 2005) reported either SWD or fatigue in children and adolescents who sustained TBI. Taken together, the results suggest that SWD and feelings of fatigue can persist several years post-injury, although these problems generally appear to diminish over the course of time.

Study outcomes

Diverse types of SWD were reported in the literature reviewed; excessive daytime sleepiness, fragmentation of sleep (frequent nocturnal arousals), and longer sleep onset latency (difficulty falling asleep) were the most commonly reported manifestations of SWD after pediatric TBI. Rhythmic movement disorder and delayed sleep phase syndromes were also reported in case studies (Drake, 1986; Nagtegaal et al., 1997; Patten & Lauderdale, 1992). Unfortunately, the nature of sleep difficulties encountered by participants and patients with TBI was not always detailed, and this was particularly the case in studies that used subjective measures of sleep such as questionnaires and interviews. For example, some studies reported positive responses to questions such as "Did sleep disorders occur in your child shortly after the head trauma?" (Necajauskaite et al., 2005) but the nature of the sleep problems was not specified or described (Hilger & Bagłaj, 2009; Hooper et al., 2004; Korinthenberg et al., 2004; Nacajauskaite et al., 2006; Necajauskaite et al., 2005; Tham et al., 2012).

Stores and Stores (2013) highlight the importance of precisely defining the terms "sleep disturbances", "sleep problems", and "sleep disorders" to garner a more accurate picture of these manifestations and improve post-TBI care. They also suggest that when these distinctions are not made, inappropriate treatment is more likely because of inaccurate diagnosis. Moreover, it is particularly important to define the type of SWD afflicting children who have had a TBI because this provides potential information regarding the underlying causes of the problem in relation to brain damage.

As for symptoms related to fatigue, most studies did not elaborate on the nature or severity of these symptoms. It was obvious, however, that fatigue (also described as "tiredness") was one of the most frequently reported symptoms, along with other post-concussive symptoms such as headaches. The percentage of patients reporting fatigue problems as a persistent symptom post-TBI reached 74% in the study by Falk (2013), which assessed fatigue 3–5 weeks after the injury. In terms of symptom progression over time, results were heterogeneous because the majority of studies reported a decrease in symptoms over time, while results from Aaro Jonsson and colleagues (2014) suggest that fatigue remains one of the most persistent symptoms of TBI even 13 years post-injury.

Study methodologies

Assessment of SWD and fatigue. The majority of studies included in the current review exclusively used subjective measures of sleep and/or fatigue; 17 of 24 studies based their conclusion solely on indirect sources, including questionnaires completed by either the patient or the caregiver, sleep diaries, and/or interviews (Beebe et al., 2007; Blinman et al., 2009; Hooper et al., 2004; Tham et al., 2012). For fatigue assessment, authors relied on questionnaires that are designed to document a broader range of post-concussive symptoms, such as the Rivermead Postconcussion Symptoms Questionnaire (King, Crawford, Wenden, Moss, & Wade, 1995). In such studies, fatigue was therefore evaluated only as a one-dimensional construct.

Well-validated and more comprehensive multidimensional instruments do, however, exist to assess fatigue in the pediatric population. For example, the Pediatric Quality of Life Inventory Multidimensional Fatigue Scale (Varni, Burwinkle, & Szer, 2004) is an 18-item questionnaire comprising three subscales (general fatigue, sleep/rest fatigue, and cognitive fatigue), allowing for a more detailed qualitative understanding. It has been validated with clinical populations (e.g., pediatric obesity and type 1 diabetes) and shows good psychometric properties.

The questionnaires used to assess sleep were varied. Only one questionnaire was used in more than one study—namely, the Children's Sleep Habits Questionnaire (Owens, Spirito, &

McGuinn, 2000). The Child Behavior Checklist (Achenbach & Edelbrock, 1991), which includes a sleep subscale, and the Epworth Sleepiness Scale (Johns, 1991) are examples of other questionnaires that have been used. Questionnaires targeting a broader range of post-concussive symptoms (e.g., Rivermead Postconcussion Questionnaire; King et al., 1995) were also used to screen for fatigue and/or SWD; however, the questions included are generally imprecise, making it difficult to determine what types of SWD are experienced.

As mentioned above, the use of objective methods was relatively rare. Polysomnography, which is considered the gold standard of sleep assessment methods, was only used in three studies of 22 (Busek & Faber, 2000; Dhondt et al., 2009; Kaufman et al., 2001). Actigraphy was also relatively uncommon because it was used in only four studies (Kaufman et al., 2001; Milroy et al., 2008; Nagtegaal et al., 1997; Sumpter et al., 2013). An actigraph is similar to a wristwatch, but contains an accelerometer that records movement to determine sleep and wake episodes. Only one study, a case report, included physiological measures of endogenous circadian rhythms (e.g., melatonin level and body temperature; Nagtegaal et al., 1997).

The primary reliance on subjective sleep measures is a serious concern given evidence from both adult and pediatric studies that there is a poor correlation between subjective reports and direct, objective measures of sleep (Simard, Bernier, Bélanger, & Carrier, 2013; Zhang & Zhao, 2007). Patients generally tend to underestimate their number of nocturnal awakenings and overestimate sleep latency in both self and third party reports (Baker, Maloney, & Driver, 1999; Tremaine, Dorrian, & Bluden, 2010). Such discrepancies are compounded when parents are asked to estimate their child's sleep.

Werner and associates (2008) argue that parents are not always aware of their child's sleep behaviors. For example, parents may not necessarily realize that their child has woken during the night, nor at what time the child woke in the morning. A study by Simard and coworkers (2013) illustrates this point. When comparing sleep diaries completed by parents and actigraphy recording data, parents report longer sleep and shorter durations of wakefulness compared with actigraphy assessment, suggesting that parents tend to overestimate their children's sleep duration. Acebo and colleagues (2005) suggests that the quantity and duration of children's nocturnal awakenings are higher when assessed with actigraphy than with maternal diary reports.

Methodological studies assessing the validity of subjective sleep assessment tools also support the concern that objective and subjective sleep data may be inconsistent. Chervin and Aldrich (1999) found that the Epworth sleepiness scale (Johns, 1991), a widely used questionnaire that assesses daytime sleepiness, was not significantly associated with the Multiple Sleep Latency Test (Carskadon et al., 1986), an objective tool for measuring the same construct.

In the adult literature, objective sleep assessment methods, such as polysomnography, are more frequently used than in pediatric populations (Castriotta & Lai, 2001; Shekleton et al., 2010). Questionnaires, interviews, and sleep diaries are also used but more as complementary tools than principal outcome measure. This is likely to be a function of the disadvantages of polysomnography recordings, which make measurement in younger populations more challenging and less feasible. Subjective measures thus remain a primary source of information in populations and age groups who may be less compliant with more invasive measures and when specialized equipment is not accessible.

To undergo comprehensive polysomnography, subjects must generally come to a hospital or clinical setting for a full night of recording; the procedure can provoke anxiety, which can affect the quality of sleep, and the equipment (e.g., electrodes) can be uncomfortable and induce difficulty falling asleep and maintaining sleep. Indeed, Stores and coworkers (1998) suggest that sleep quality and quantity is better when it is assessed in the home setting.

Home polysomnography (also known as unattended ambulatory polysomnography) has been used for this purpose in a few studies involving pediatric populations and appears to be a more suitable method for use with children than laboratory polysomnography (Bélanger, Bernier, Paquet, Simard, & Carrier, 2013; Brockmann, Perez, & Moya, 2013; Stores et al., 1998). Literature on the feasibility of this method remains sparse, however.

Actigraphy is a more feasible alternative for recording in the natural sleep environment and has been validated for use with preschool children, although it remains an indirect method for assessing sleep (via accelerometry; Bélanger et al., 2013; Sadeh, 2011). It has been used with success in both typically developing children (El-Sheikh et al., 2007; Simard et al., 2013) and clinical pediatric populations (Corkum, Tannock, Moldofsky, Hogg-Johnson, & Humphries, 2001; Wiggs & Stores, 2004). Moreover, it is cost-effective and shows reasonable validity and reliability (Sadeh, 2011).

Pre-injury assessment of SWD and/or fatigue. Few studies (4 of 24) included pre-injury measures of SWD or fatigue. This is a concern because it is has been established that children who sustain TBI tend to display more behavioral problems before the accident and that these behavioral problems are actually a risk factor for TBI (Gerring et al., 1998; McKinlay et al., 2010). Thus, SWD and fatigue may be associated with this pre-existing risk factor and compounded by the TBI. Tham and associates (2012) and Beebe and colleagues (2007) report that pre-injury SWD were higher in the mild-moderate TBI groups compared with an OI control group. Sumpter and coworkers (2013) and Shay and colleagues (2014) also reported retrospective ratings of SWD but did not specify whether the TBI and control groups were equivalent in terms of SWD and fatigue before the injury. Shay and associates (2014), however, used pre-injury sleep ratings as a covariate in the analysis, which is good statistical practice to control for pre-injury levels.

Sample sizes and composition. Sample sizes ranged considerably among the studies reviewed. Given that a few studies were case reports and others had a total sample size inferior to 100 (Aaro Jonsson et al., 2014; Blinman et al., 2009; Kaufman et al., 2001), we remain conservative in the interpretation of the results. In spite of this, a substantial number of studies had larger sample sizes (Hilger & Bagłaj, 2009; Hooper et al., 2004; Schneider et al., 2010; Tham et al., 2012), and results from studies with relatively small samples ($N<100$) align with those of larger studies. Taken together, these results provide more robust evidences that SWD and fatigue are common after pediatric TBI.

In addition, the present review highlights the diversity in sample composition among studies in pediatric TBI. Some authors focused on a single TBI severity group, whereas others looked at various levels of severity. When multiple severity levels are included in the TBI group, we suggest that results should be reported separately for each group, as in Beebe and colleagues (2007) and Osorio and associates (2013). Unfortunately, in several studies, the results were collapsed across groups (Aaro Jonsson et al., 2014; Falk, 2013; Hooper et al., 2004; Osorio et al., 2013; Sumpter et al., 2013; Tham et al., 2012). This impedes the interpretation of post-TBI outcomes, because the nature and severity of SWD and fatigue cannot be linked to the severity of the TBI. Nevertheless, most studies reported increased in SWD and/or fatigue regardless of TBI severity.

Lastly, TBI severity was not defined consistently across studies. For example, Ponsford and coworkers (1999) defined mild TBI with a Glascow Coma Scale (GCS) score of 13 to 15, whereas Blinman and associates (2009) defined it based on a GCS of 14 or 15.

Control groups. Several studies did not use a control group despite knowledge that sleep problems may occur after other type of injuries, including OI (Kaufman et al., 2001). For example, Tham and coworkers (2012) reported that both TBI and OI groups displayed increased sleep disturbances after the injury. Numerous factors may explain the presence of increased sleep problems after OI, such as the stress induced by the accident or pain causing increased nighttime waking. Consequently, the inclusion of a control group seems imperative to determine whether sleep problems are specific to brain insult.

Age of TBI populations and development. In addition to an underutilization of objective measures in the study of post-TBI pediatric SWD and the low frequency of control group inclusion, the present review highlights a lack of research on younger children, toddlers and preschoolers. Only one article retained for review specifically targeted preschoolers (Shay et al., 2014). A few studies included younger children (Falk, 2013; Hilger & Bagłaj, 2009; Hooper et al., 2004; Korinthenberg et al., 2004; Tham et al., 2012), although they were combined with older children and adolescents through to 18 years and the exact proportion of younger children is unknown, preventing any conclusions specific to younger children.

It is clear that among the 24 articles included in this review, this age group is largely underrepresented despite the relative overrepresentation of children under the age of 5 in epidemiological studies of pediatric TBI. Recent epidemiological data indicate that the risk of mild TBI is extremely high in children under 5 years of age (McKinlay et al., 2008), with birth cohort data indicating that children between 0 and 5 years constitute a high-risk group with a yearly TBI rate of 1.85 per 100 children (compared with rates of <1.17 in other pediatric age groups; McKinlay et al., 2008). Consistent with this peak, chart reviews of emergency department (ED) presentations and registries indicate that children under age 5 have the highest attendance rates for suspected brain injury, mostly because falls from heights and being dropped (Crowe, Babl, Anderson, & Catroppa, 2009; Crowe, Anderson, Catroppa, & Babl, 2010; Hawley, Ward, Long, Owen, & Magnay, 2003; Rutland-Brown, Langlois, Thomas, & Xi, 2006).

This underrepresentation is all the more critical considering young children undergo major maturational changes in cognitive, affective, and social domains during this period and that sleep is critical to these developmental processes. A growing number of studies targeting typically developing children report that insufficient or poor-quality sleep at a young age is associated with poorer cognitive performance, increased behavioral problems, and social difficulties (Astill et al., 2012; Beebe, 2011; Bernier, Beauchamp, Bouvette-Turcot, Carlson, & Carrier, 2013; Bernier et al., 2010; Randazzo, Muehlbach, Schweitzer, & Walsh, 1998). There is a considerable and nonnegligible gap in the TBI-sleep literature in this regard. Pediatric TBI increases the risk of SWD, while also disrupting cognitive, behavioral, and social functions. Because SWD in young children are known to compromise the development of these functions, suffering a TBI during childhood presents a double hazard, which may multiply the deleterious consequences of early brain injury.

Among cognitive domains, higher-order processes such as executive functioning appear to be particularly associated with sleep (Anderson, Storfer-Isser, Taylor, Rosen, & Redline, 2009; Sadeh, Gruber, & Raviv, 2002). The strong link between sleep and executive functioning is believed to be because the prefrontal cortex is one of the brain areas that benefits the most from sleep (Horne, 1993). Consequently, higher-order cognitive functions, which are dependent on proper functioning of the prefrontal cortex, are particularly affected by SWD. In parallel, it is known that the frontal lobes are among the brain areas that are the most vulnerable to TBI

(McAllister, 2011). Children who sustain frontal tissue damage may therefore experience cognitive dysfunction either as a result of injury location or TBI-related SWD, or a combination of the two.

A prospective association between sleep in infancy and later higher-order cognitive functioning was demonstrated by Bernier and colleagues in 2010. Their study revealed that a higher ratio of nighttime sleep at age 1 was related to better subsequent executive functioning. In 2013, Bernier and associates further demonstrated this point in which children showing more consolidated sleep as infants performed better on abstract reasoning, concept formation, and problem-solving tasks 3 years later. To summarize, there is evidence that sleep quality at a young age can impact the development of high-order cognitive processes. In parallel, it is known that TBI sustained in childhood can also impair executive functioning (Ganesalingam et al., 2011; Levin & Hanten, 2005; Sesma, Slomine, Ding, & McCarthy, 2008). Therefore, these problems may be exacerbated by SWD subsequent to TBI. Further studies are needed to more precisely evaluate the impact of TBI on sleep, with the aim of reducing later cognitive dysfunctions.

In sum, there is a modest but consensual body of empirical evidence highlighting the high prevalence of SWD and fatigue after pediatric TBI. Methodologies used, however, are mainly subjective, and these types of assessment methods yield sleep estimates that may significantly differ from objective data. Moreover, there is a lack of sleep literature targeting younger children with TBI, despite substantial evidence that SWD may compromise early cognitive, behavioral, and social development.

Even if clinicians are increasingly aware of the impact of SWD on post-TBI clinical prognosis, this aspect of patient care is often inadequately considered. Future studies should seek to understand the pathophysiological mechanisms that may underlie post-TBI SWD to provide more appropriate care, target interventions, and limit the functional impact of childhood TBI.

Limitations

This systematic review of the literature has some limitations that must be taken into consideration when interpreting the results. First, some limitations in the conclusions that are possible are inherent to the methodologies used in the studies reviewed. As mentioned above, few studies included a control group, pre-injury measures, and objective measures of SWD and/or fatigue. Moreover, several studies did not separate the results regarding TBI severity, and the nature of SWD encountered in patients with TBI was not always detailed. As highlighted in our quality assessment, some studies had potential risks of bias related to study participation, study attrition, and outcome measurement.

This work also has some limitations related specifically to the review methodology used. For example, we did not explore the grey literature; therefore, studies that were not formally published, even though they documented SWD and/or fatigue in conference presentations or posters, were not considered in this review. Moreover, we limited our search criteria to French and English and to four databases. It is possible that some articles that would have corresponded to our inclusion/exclusion criteria were not retrieved. Despite these limitations, because there is a strong agreement across the studies we retained, it is unlikely that the conclusions drawn would be significantly different if these limitations were countered.

Conclusions

The current systematic review focused on documenting the putative presence of persistent SWD and fatigue after pediatric TBI. Empirical data support a general picture illustrating the prevalence of inadequate sleep among children and adolescents who sustain TBI, regardless of the severity of the injury. Moreover, fatigue symptoms were often described as one of the most frequently reported post-concussive symptoms. Few studies, however, have focused on the very youngest age group of children, who are particularly at risk for TBI. Sleep assessment methods are mainly subjective, which can lead to several biases. More longitudinal and experimental studies are recommended to gain better insight into this issue. Moreover, it is known that children who sustain brain injury are at high risk for cognitive deficits, especially high-order cognitive processes, and that SWD exacerbate such problems. It appears of paramount importance to better address and document sleep difficulties in the management of pediatric TBI.

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Table 1

Details of the 24 articles retained for systematic review

Author, year	*TBI group characteristics (age range at injury in years)*	*Control group characteristics (age range at injury in years)*	*Assessment of sleep and/or fatigue*	*Time since injury*	*Main results related to SWD*	*Main results related to fatigue*
Aaro Jonsson et al., 2014	N = 21 mild to severe TBI (1-16)	N/A	Subjective (Swedish version of Mayo-Portland Adaptability Inventory)	13 years	N/A	Fatigue was one of the highest-rated problems, along with concentration, irritability and transportation
Beebe et al., 2007	N = 56 moderate TBI (6-12) N = 53 severe TBI (6-12)	N = 80 OI (6-12)	Subjective (Child Behavior Checklist sleep subscale completed by parents)	6, 12 and 48 months	The moderate TBI and OI injury groups displayed a small decline in sleep problems from pre- to post-injury whereas children with severe TBI displayed increased post-injury sleep problems.	N/A
Blinman et al., 2009	N = 63 mild TBI (11-17)	N/A	Subjective (questionnaire from imPACT program completed by patient)	Baseline and follow-up 2-3 weeks after injury	At 2-3 weeks after TBI, 38.1% still reported trouble falling asleep, 33.3% sleeping more than usual, 22.2% sleeping less than usual and 27% drowsiness. Overall symptoms improved significantly between enrolment and follow-up.	At 2-3 weeks after TBI, 30.2% still reported fatigue compared to 67.2% at the initial visit.

Busek & Faber, 2000	N = 2 moderate TBI (14 and 16) N = 1 severe TBI (15)	N/A	Objective (daytime EEG and PSG)	6 to 8 months for the PSG and not mentioned for the EEG	REM sleep is the most sensitive to traumatic damage in the brain. Elevated percentage of wakefulness, prolonged sleep latency and fragmentation of sleep by many arousal reactions is very common, mostly in patients after severe brain injury.	N/A
Dhondt et al., 2009	N = 1 mild TBI (5)	N/A	Objective (overnight video-EEG and PSG)	2 months	The patient presented with excessive daytime sleepiness. An overnight video-EEG showed a fragmented sleep with confusional arousals, night terrors and many limb movements. Nocturnal PSG yielded a sleep latency of 4.8 min, no sleep-onset REM and an increased awakening-index (27.4/h).	N/A
Drake, 1986	N = 1 severe TBI (16)	N/A	Objective (prolonged EEG and with videotape monitoring)	6 months	Participant showed bodily thrashing, headrocking, and moaning during sleep. EEG showed that her episodes were not post-traumatic seizure but rather episodes of rhythmic movement disorder.	N/A
Falk, 2013	N = 149 mild to moderate TBI (0-16)	N/A	Subjective (Rivermead Postconcussion Questionnaire completed by the patient and/or the parent)	3 to 5 weeks after injury	N/A	74% of patients reported tiredness, which was the most commonly reported symptoms after headache.

Hilger et al., 2009	N = 353 mild TBI (3-18)	N/A	Subjective (homemade questionnaire including 17 questions referring to potential late effects of the head injury completed by parents)	6 months after hospital discharge	Of all 353 responders, 20.4% reported sleep disturbances, and among the 151 responders who noted symptoms related to mTBI, 47.7% reported sleep disturbances.	Of all 353 responders, 16.9% reported fatigue, and among the 151 responders who noted symptoms related to mTBI, 39.7% reported fatigue.
Hooper et al., 2004	N = 681 mild to severe TBI (0-18)	N/A	Subjective (structured telephone interview with the caregiver)	1, 4 and 10 months	At one-month follow-up, 14.7% reported sleep problems. At four-month follow-up, 10.7% reported sleep problems. At ten-month follow-up, 0% reported sleep problems.	At one-month follow-up, 11.3% reported fatigue. At four-month follow-up, 11.5% reported fatigue. At ten-month follow-up, 4.9% reported fatigue.
Kaufman et al., 2001	N = 19 mild TBI (M = 13.5)	N = 13 TDC for PSG data (M = 13.3) N = 15 TDC for actigraphic recording (M = 13.6) N = 16 TDC for quest. data (M = 13.3)	Objective (actigraphy and PSG) and subjective (homemade questionnaire related to post-concussive symptoms completed by the patient)	3 years	Three years after mTBI and without any other discernible clinical sequel, adolescents still complained of significant sleep problems and that was confirmed by objective sleep monitoring. The main symptoms were decreased sleep efficiency, with increased wake time and more frequent prolonged awakenings from sleep. Data revealed that TBI patients suffered from significant insomnia.	N/A
Korinthenberg et al., 2004	N = 98 mild TBI (3-13)	N/A	Subjective (structured interview with the parent; of note, EEG was also used in the study but not as a measure of sleep)	Baseline and follow-up at 4 to 6 weeks	At 4-6 weeks post-injury, 10 patients still complained of sleep disturbances. Number of patients complaining of sleep disturbances at baseline wasn't provided.	At 4-6 weeks post-injury, 13 patients still presented increased fatigue (compared with 88 at baseline).

Milroy et al., 2008	N = 18 mild TBI (M = 7.6)	N = 30 OI (M = 7.6)	Objective (actigraphy) and subjective (Children's Sleep Habits Questionnaire and Strengths and Difficulties Questionnaire completed by parents; Self-Report Sleep Scale completed by patient)	6 months to 4 years	Parents reported greater sleep disturbance in the mild TBI group. No significant differences were found in parental ratings of daytime sleepiness, child-reported sleep difficulties, or objective actigraph measures. There was no significant correlation between questionnaires total scores and actigraph measures of sleep efficiency.	N/A
Nacajauskaite et al., 2006	N = 102 mild TBI (4-15*)	N = 102 OI (4-15*)	Subjective (homemade questionnaire including demographic data child's health status completed by the parent)	Median time: 27 months	There was no significant difference between groups in terms of sleep disorders (frequency and severity). However, the more parents reported sleep disturbances, the more they were concerned about their child having a brain disorder.	There was no significant difference between groups in terms of fatigability (frequency and severity).
Nagtegaal et al., 1997	N = 1 (severity not mentioned; 15)	N/A	Objective (plasma melatonin, body temperature, wrist activity and sleep architecture via EEG)	6 weeks	Following TBI, plasma melatonin, body temperature, wrist activity and sleep architecture (EEG) were delayed by almost half a day.	N/A

Necajauskaite et al., 2005	N = 102 mild TBI (4-16*)	N = 102 OI (4-16*)	Subjective (homemade questionnaire including questions about the child's health status completed by the parent)	1 to 5 years	The prevalence of sleep disorders did not differ significantly between the TBI and the OI group. 16.7% of parents of the TBI group answered positively to the question "did sleep disorders occur in your child shortly after head trauma?" Results also revealed that significantly more parents (from both groups) answered positively when asked if their child experienced sleep disorders in the last year then in the last month suggesting a decrease in sleep problems overtime.	N/A
Osorio et al., 2013	N = 42 complicated mild TBI (12-18) N = 60 moderate-severe TBI (12-18)	N/A	Subjective (Parent-Report Sleepiness Scale completed by parents and Epworth Sleepiness Scale completed by patient)	M = 14.9 weeks after injury	Based on the parent report, 51% of adolescents with moderate-to-severe TBI showed significant daytime somnolence compared with 22% of those with complicated mild TBI. Daytime somnolence reported by parents correlated with TBI severity.	N/A
Overweg-Plandsoen et al., 1999	N = 22 mild TBI (4-14*)	N = 22 fracture boned patient (4-14*)	Subjective (standardized questionnaire with yes or no question completed by the caregiver)	2 years	N/A	In the TBI group, fatigue was significantly more reported by parents than in the control group.
Patten et al., 1992	N = 1 severe TBI (13)	N/A	Subjective (evaluation by medical staff)	In the weeks after the injury	Patient exhibited sleep-wake schedule disorder after TBI.	N/A

Pillar et al., 2003	N = 98 mild TBI (8-18*)	N = 80 healthy subjects (8-18*)	Subjective (homemade questionnaire completed by patient)	6 months to 6 years	The prevalence of sleep disturbances was significantly larger in the TBI group (28% versuss 11%). Within the TBI group, those who developed long-term sleep disturbances had a greater body mass index and poorer parental education compared with those who did not develop sleep disturbances.	N/A
Ponsford et al., 1999	N = 130 mild TBI (6-15)	N = 96 with minor injuries not involving the head (6-15)	Subjective (structured interview with the parent and Postconcussive Syndrome Checklist completed by parents and children)	1 week and 3 months	N/A	At 1 week post injury, TBI group reported significantly more frequent fatigue than did controls but at 3 months post-injury, no significant difference was found.
Schneider et al., 2010	N = 781 with history of concussion (9-17)	N = 3412 without history of concussion (9-17)	Subjective (Sport Concussion Assessment Tool completed by patient with assistance of parent when needed)	not mentioned	Children with previous history of concussion reported sleeping more than usual and more difficulty falling asleep compared to children with no previous history of concussion. However, it is not mentioned if these differences are statistically significant.	Fatigue and drowsiness were more commonly reported symptoms among children with previous history of concussion than children with no previous history of concussion. However, it is not mentioned if these differences are statistically significant.

Shay et al., 2014	N = 20 severe TBI (M = 4.8) N = 55 complicated mild/moderate TBI (M = 5.0)	N = 92 OI (M = 5.2)	Subjective (Children's Sleep Habits Questionnaire completed by parents)	6, 12 and 18 months	The total sleep problems score was higher in children with TBI at 6 months post-injury and sleep duration was shorter at 6 and 12 months. Children in the sTBI group displayed more bedtime resistance than children in the other two groups. For all groups, sleep problems predicted more emotional/ behavioral problems and worse everyday executive function.	N/A
Sumpter et al., 2013	N = 15 moderate to severe TBI (5-16)	N = 15 siblings (5-16)	Subjective (Sleep diary, family interview to establish sleep history, Children's Sleep Habits Questionnaire completed by parents and children) and objective (actigraphy)	9 to 65 months	Significantly more sleep problems were parent-reported, self-reported, and actigraph-recorded in the TBI group. The TBI group had poorer sleep efficiency and longer sleep latency than their siblings.	N/A
Tham et al., 2012	N = 729 mild to severe TBI (2-17)	N = 197 OI (2-17)	Subjective (one item of the Pediatric Quality of Life Inventory completed by parents)	3, 12, and 24 months	Both groups (TBI and OI) displayed increased sleep disturbances after injury. However, TBI group experienced higher severity and more prolonged duration of sleep disturbances compared to OI group.	N/A

Note. SWD = sleep-wake disturbances; TBI = traumatic brain injury; OI = orthopedic injuries; PSG = polysomnography; EEG = electroencephalography; REM = rapid eye movement.
*Age at assessment is provided when age at injury was available.

Table 2

Potential risk of bias of the 24 articles included for systematic review

Author, year	*Participation*	*Attrition*	*Outcome*	*Confounding*	*Analysis*
Aaro Jonsson et al., 2014	Partly	No	No	No	Partly
Beebe et al., 2007	No	No	No	No	No
Blinman et al., 2009	Partly	Partly	No	No	Partly
Busek & Faber, 2000	Partly	NA	No	No	No
Dhondt et al., 2009	Partly	No	Partly	No	NA
Drake, 1986	Partly	NA	Partly	No	NA
Falk, 2013	No	Unsure	No	Partly	Partly
Hilger et al., 2009	No	Yes	Partly	No	Partly
Hooper et al., 2004	No	No	Partly	No	No
Kaufman et al., 2001	Partly	No	No	No	Partly
Korinthenberg et al., 2004	No	No	No	No	No
Milroy et al., 2008	No	Partly	No	No	No
Nacajauskaite et al., 2006	No	Yes	No	No	No
Nagtegaal et al., 1997	Yes	NA	No	No	NA
Necajauskaite et al., 2005	No	Yes	No	No	No
Osorio et al., 2013	No	No	No	No	No
Overweg-Plandsoen et al., 1999	No	No	Yes	No	No
Patten et al., 1992	Partly	NA	Unsure	No	NA
Pillar et al., 2003	Partly	No	Yes	No	No
Ponsford et al., 1999	Partly	No	No	No	No
Schneider et al., 2010	No	No	Partly	Partly	No
Shay et al., 2014	No	No	No	No	No
Sumpter et al., 2013	No	Partly	No	No	No
Tham et al., 2012	No	No	Yes	No	No

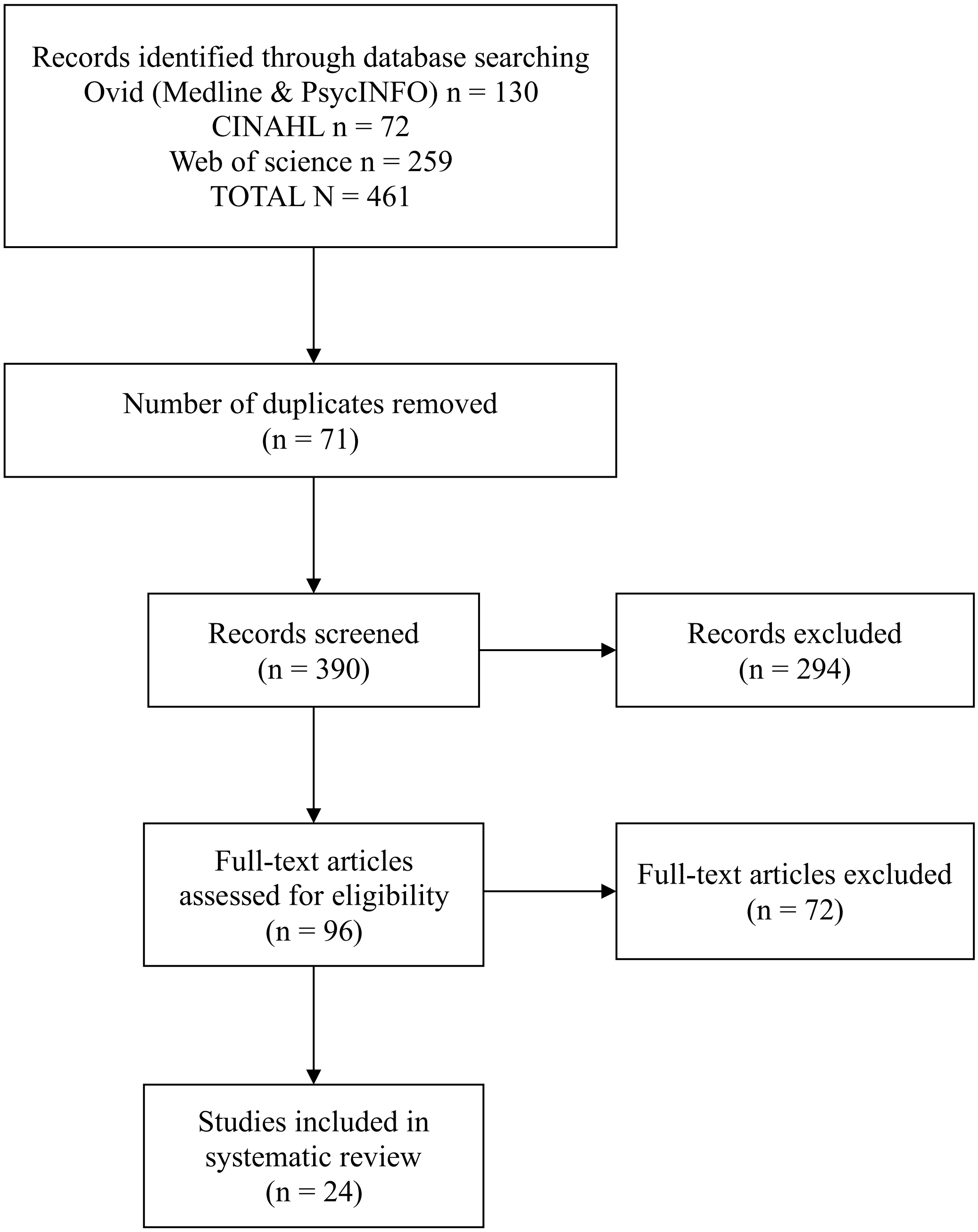

Figure 1. Flow chart documenting process of article selection for review

ANNEXE B : Article 4

Should Young Children with Traumatic Brain Injury Be Compared with Community or Orthopedic Control Participants?

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Abstract

Pediatric traumatic brain injury (TBI) research depends on comparisons of profiles and outcome between brain injured individuals and groups consisting either of injured controls (e.g., orthopedic injuries, OI) or uninjured, typically developing children recruited from the community (community controls, CC). Children with OI are thought to provide optimal comparisons for individuals with TBI because they share injury-related experiences and pre-morbid characteristics; however, a study by Mathias and colleagues (2013) in adults has called into question the added value of injury control groups in TBI research. The comparability of these control groups has not been established in young children. 72 children with OI and 84 CC aged between 18 and 60 months were compared on a range of demographic variables, developmental and medical history, pre-injury behavioral and adaptive profiles, as well as on measures of adaptive functioning, behavior, family functioning, post-concussive symptoms and cognition (intellectual functioning, verbal abilities, executive functioning, social cognition) six months after the OI. There were no statistically significant differences between the OI and CC groups on any of the variables tested, whether they related to pre-injury or post-injury characteristics. The findings are applicable to studies seeking to identify appropriate control groups in the context of preschool TBI research, and suggest no clear advantage in recruiting OI controls based on the variables studied and the methodology used. However, further work is necessary to verify additional factors and outcomes relevant to pediatric TBI research, as well as to compare outcome between these two groups at more acute stages (i.e. prior to 6 months post-injury).

Keywords : community controls; injured controls; pediatric brain injury; traumatic brain injury.

Introduction

Childhood traumatic brain injury is a prevalent health problem that can lead to physical, cognitive, behavioral, and social changes in development (Catroppa, Anderson, Beauchamp, & Yeates, 2015). In its mildest form (mild TBI [mTBI] or "concussion"), alterations in functioning are typically reported to be more transient and less pervasive than after more severe injuries, leading to good prognosis (Anderson, Catroppa, Morse, Haritou, & Rosenfeld, 2005a; Asarnow et al., 1995; Babikian et al., 2011; Bijur & Haslum, 1995; Brooks et al., 2013; Carroll, Cassidy, Holm, Kraus, & Coronado, 2004; Fay et al., 1993; Hung et al., 2014; Rieger et al., 2013; Studer et al., 2014; Yeates, 2010), though some data suggest that a minority of children may suffer from more chronic difficulties and persistent symptoms (Babikian & Asarnow, 2009; Wood, 2004). Some controversy exists, however, as to whether changes in functioning after mTBI are brain-injury specific, or whether they represent more general injury effects that may also be present in other traumatically injured groups, such as those with orthopedic injuries (Satz et al., 1997). Alternately, it has also been suggested that difficulties, or more protracted recovery periods following mTBI, may simply reflect the presence of problems that pre-date injury (Babikian, McArthur, & Asarnow, 2013; Carroll et al., 2004).

Related to this issue, there is a debate as to what type of control group offers the best comparative approach for accurately reporting mTBI outcomes, and controls for potential pre-morbid problems and the medical experience. Non-injured children recruited from the community ("community controls (CC)" or "typically developing controls") are most often used in pediatric mTBI studies, notably because they are numerous, accessible, and less costly to recruit. In addition, they are thought to be representative of population-level functioning and standardized test norms (Mathias, Dennington, Bowden, & Bigler, 2013), and offer the opportunity to compare children with TBI to the peers they are likely to be contrasted with in daycare, school, recreational and community settings. Orthopedically injured control groups, on the other hand, have the advantage of being more comparable to those with mTBI at an experience-level because they go through similar medical processes (e.g., presentation to the Emergency Department, radiological exams, minor medical interventions, medication for pain, stress, etc. ;Yeates, 2010). Children who sustain orthopedic injuries are also thought to present similar pre-morbid (e.g., attention problems, behavior) characteristics to those who incur mTBI, which may place them at similar risk for sustaining injury (Asarnow et al., 1995; Gerring et al., 1998; McKinlay et al., 2010). Demographic factors (e.g., socioeconomic status, congested living) and parenting practices (e.g., parental alcohol misuse, psychiatric history, unsupervised play) may also increase the risk of accidental injuries (Goldstrohm & Arffa, 2005; Klonoff, 1971; Winqvist, Jokelainen, Luukinen, & Hillbom, 2007). However, despite studies reporting elevated pre-morbid attention and behavioral problems in children who sustain brain injury (Levin et al., 2007; Max, Sharma, & Qurashi, 1997; Yeates et al., 2005), there is little direct evidence showing that the prevalence is comparable to that of other injury groups.

In one of the largest studies of pediatric mTBI outcome to date, Babikian and colleagues found that when the effects of pre-injury risk factors and general injury experience are controlled for by comparing children with mTBI to an "other injury" control group, there was no evidence of long-term cognitive impairment in the mTBI group (Babikian et al., 2011). However, children with mTBI did show performance differences when compared to a non-injury control group, suggesting a general injury rather than a brain injury-specific effect. This and other studies (e.g., Bijur, Haslum, & Golding, 1990; Ettenhofer & Barry, 2012; Yeates, 2010) support the idea that injured control groups are the most methodologically sound choice for pediatric mTBI research.

Mathias and colleagues revisited the TBI control group debate in an adult population by directly investigating the comparability of community and orthopedic injury control groups aged 18-80 years across a range of demographic, background, psychosocial, and cognitive variables, and found no statistically significant group differences other than on rate of alcohol use, which did not correlate with common variables of interest in TBI research (Mathias et al., 2013). The authors concluded that there appears to be no clear advantage in recruiting an injury control group in adult TBI research. It is possible, however, that the comparability of adult control groups does not extend to pediatric populations, as factors of influence are likely to be different. For instance, children are more subject to environmental influences such as parental education and family functioning than are adults. Children also typically have greater inter-individual variability in functioning because of normal variations in developmental trajectories and reliance on more diffuse cognitive and social brain network (Uddin, Supekar, & Menon, 2010). Differences between the two types of control groups may also be lessened in adults because of the greater adherence of adults to societal norms and expectations, and their increased ability to regulate and compensate for potential behavior or pre-morbid problems.

Children who sustain TBI before the age of six (i.e., preschoolers) represent a particular portion of the TBI population in which the choice of control group is especially relevant to study. First, TBI during this period is highly prevalent, with birth cohort data indicating an annual TBI rate of 1.85 per 100 children aged 0 and 5 years, compared to rates of < 1.17 in other pediatric age groups (McKinlay et al., 2008). Second, children of this age who sustain injury are likely to be highly vulnerable to adverse outcomes because any disruption in the acquisition or consolidation of rapidly emerging skills has the potential to set them back from typical developmental trajectories (Anderson, Catroppa, Morse, Haritou, & Rosenfeld, 2005b; Anderson & Moore, 1995). Third, preschoolers have short developmental histories in comparison to older pediatric age groups and adults and therefore less is known about their pre-morbid status. To date, researchers have used either CC or OI groups exclusively in their comparisons of preschoolers who sustain TBI to control participants. Whether they have favored CC (Crowe, Catroppa, Babl, & Anderson, 2012; Ewing-Cobbs et al., 2006) or opted for OI (Yeates, Taylor, Walz, Stancin, & Wade, 2010) groups, analyses have tended to show adequate matching on standard demographic variables such as age and socioeconomic status. However, these basic comparisons do not inform on other potential areas of dissimilarity between groups, such as behavior, family functioning or cognition.

The objective of this study was therefore to address the question of optimal control group selection in pediatric TBI research, with a particular focus on those that are the most vulnerable, i.e., children under five years of age. Specifically, we aimed to compare orthopedic injury controls with community controls between the ages of 18 and 60 months on a range of variables relevant to development and to TBI, including demographics, developmental and medical history, behavior and adaptive functioning, family factors, post-concussive symptoms, global cognition, and aspects of social cognition and executive functioning.

Method

Participants

As part of a prospective, longitudinal study on the consequences of early TBI, two groups of control participants were recruited and compared: 72 children who sustained orthopedic injury (OI) were identified at an tertiary urban Emergency Department and 84 typically developing children were recruited from the community (community controls, CC). Inclusion criteria for the OI group were (a) age at injury between 18 and 60 months; (b) limb trauma leading to a final diagnosis of simple fracture, sprain, contusion or unspecified trauma to an extremity. The CC were aged between 24 and 66 months in order to be of comparable age to the OI at post-injury assessment time points. The following exclusion criteria were applied for all participants; (a) diagnosed congenital, neurological, developmental, psychiatric, or metabolic condition; (b) less than 36 weeks of gestation; (c) prior traumatic brain injury; (d) non-fluent in French or English.

Procedure

This study was approved by the Sainte-Justine Hospital Research Ethics Board. Recruitment of children who sustained OI took place in the Emergency Department of Sainte-Justine Hospital between 2011 and 2015. A research nurse approached potentially eligible participants. Once they agreed to participate, the research coordinator mailed a consent form and a pre-injury questionnaire booklet along with a sociodemographic questionnaire. The primary caregiver (90% mothers) was asked to answer the questionnaire based on their child's functioning prior to the injury. Six months later, children with OI were invited to the laboratory for a cognitive assessment and the primary caregiver completed the same questionnaire booklet (without the sociodemographic questions) along with a questionnaire pertaining to post-concussive symptoms.

The CC were recruited in daycare centers by research assistants. Given the absence of injury, the CC were tested right after recruitment, and the primary caregiver (89% mothers) completed all the questionnaires.

Measures

1. Questionnaires

ABCs Demographic Questionnaire. The primary caregiver completed this in-house developmental and demographic questionnaire. It includes information on the child's gender, handedness, ethnicity, birth characteristics, developmental and medical history. In addition, socioeconomic status (SES) was calculated using the Blishen Socioeconomic Status Scale (Blishen, Carroll, & Moore, 1987), which attributes a score based on parents' occupation. Parental education was also calculated by averaging both parents' highest educational attainment, ranging from 1 (*doctoral level)* to 8 (*less than 7 years of school*). When parental occupation and/or highest educational attainment was available for only one parent, or in the case of single parent families, no average was computed. If a child lived with one biological parent and a step-parent, we used the step-parent's information in the average.

Adaptive Behavior Assessment System (ABAS; Harrison & Oakland, 2003). The ABAS, 0–5 year version, 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). The parent must indicate 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). The Global Adaptive Composite (GAC), the Social Composite, the Practical Composite and the Conceptual Composite are reported. A higher standard score (M = 100, SD = 10) is indicative of better adaptive skills.

Child Behavior Checklist (CBCL; Achenbach & Rescorla, 2001). The CBCL for ages 1.5–5 years is a 100-item checklist completed by the parent to assess the presence of internalizing and externalizing behavior problems. The respondent must rate their child on a 3-point scale (0 = Not true, 1 = Somewhat or sometimes true, 2 = Very true or often true). The internalizing problems score (Emotionally reactive, Anxious/depressed, Somatic complaints and Withdrawn subscales) and the externalizing problems score (Attention problems and Aggressive behavior subscales) are reported. A higher standard score (M = 50, SD = 10) indicates more behavioral problems.

Family Functioning Device (FAD; Epstein, Baldwin, & Bishop, 1983). The General Functioning (GF) subscale of the FAD includes 12 items pertaining to overall satisfaction with family functioning. Each statement is rated on a 4-point scale ranging from 0 to 3. A higher score indicates poorer family functioning.

Dyadic Adjustment Scale (DAS; Spanier, 1976). The brief 4-item version of the DAS was completed by the primary caregiver as a measure of couple satisfaction. Each item is rated on a 6-point scale ranging from 0 to 5, and a higher score indicates higher marital satisfaction.

Parental Stress Index (PSI; Abidin, 1995). This questionnaire is designed to measure stress experienced in the parental role. A brief version (24 items) was administered in which the parent must answer on a 5-point scale ranging from 1 to 5. The scores from the Parental distress (PD) and the Parent-child dysfunctional interaction (PCDI) subscales are reported. The PD subscale pertains to the parent's perception of his or her own behavior (e.g., marital conflict, perceived competence, depression), whereas the PCDI subscale indicates whether the parent perceive his or her interactions with the child as satisfying or not.

Postconcussive Symptom Interview (PCS-I; Mittenberg, Wittner, & Miller, 1997). The PCS-I is a symptom checklist administered orally to parents. It evaluates the presence of 15 post-concussive symptoms in the cognitive, somatic, affective and sleep domains. Parents must indicate if the symptoms were present (score of 1) or absent (score of 0) in their child over the past week and the past six months.

2. General intellectual functioning

Global intellectual functioning and verbal abilities were measured for all participants. Children between 24 and 30 months at the time of the assessment were evaluated using the Cognitive and Language subscales of the Bayley Scales of Infant Development (Bayley-III; Bayley, 2006), and children older than 31 months completed the Wechsler Preschool and Primary Scale of Intelligence (WPPSI-III; Wechsler, 2002). The Bayley-III Cognitive composite and the Global Index of the WPPSI-III were used as indicators of general intellectual functioning, whereas the language composite of the Bayley-III and the verbal IQ of the WPPSII-III were used to reflect verbal abilities. Percentile ranks are reported, allowing direct comparison of the two cognitive tools.

3. Social cognition

False belief understanding (Bellerose, Bernier, Beaudoin, Gravel, & Beauchamp, 2015; Hughes, Ensor, & Marks, 2011). Children are presented a peep-through picture book with deceptive elements (e.g., what appears to be an eye peeping through turns out to be a spot on a snake's back) to measure false belief understanding, a subcomponent of theory of mind. They are then asked to recall their own initial false belief about what they saw and to predict another person's false belief. Scores vary between 0 and 2.

Discrepant desires and Desires tasks (Bellerose et al., 2015; Pears & Moses, 2003; Repacholi & Gopnik, 1997). Depending on their age, children completed one of two developmentally appropriate tasks measuring desires reasoning, a subcomponent of theory of mind. Those aged 24 to 35 months were administered a task during which they must choose between two foods, one typically liked by children (e.g., cookies) and one that is generally less preferred (e.g., celery). Then, the experimenter expresses a preference for the children's non-preferred food and asks for another food item. The goal of the task is to assess whether children will answer egocentrically or will consider the experimenter's preferred food. A total of four food combinations are presented, for a maximum of four points. Children aged 36 months and older completed a measure of their understanding of how fulfilled and unfulfilled desires might affect a character's feelings in a story. The stories describe a character's search for a desired object and at the end of the story, children are asked to speculate if the character is happy or sad. Six stories are presented, for a maximum score of six points.

4. Executive functions

Tower of Hanoi (planning; Welsh, Pennington, & Groisser, 1991). Children were administered Welsh's simplified version of this classic planning task. Three different sized disks must be moved amongst three pegs to recreate a goal configuration in a minimum number of moves by always placing a small disk over a larger one. Children were asked to recreate six towers, for a maximum of six points.

Delay of gratification (inhibition; Beck, Schaefer, Pang, & Carlson, 2011). Children must make a series of choices as to whether they want a smaller immediate reward or a larger delayed reward. Awards are crackers, coins, and stickers presented in small plastic containers. For example, the child must choose between a cracker to eat now, or six crackers to eat later "when all games are completed and you will return home." One point is awarded every time the child selects the delayed reward for a maximum of 9 points.

Spin the pots (working memory; Hughes & Ensor, 2005). Depending on their age, children are presented with 8-12 visually distinct boxes and 6-10 stickers. Stickers are placed in the boxes and children are encouraged to search for them. The boxes are rotated from one trial to the next so that the child must keep in mind where they have searched and found stickers previously. The task ends when the child has found all the stickers or when the maximum number of spins has been reached (12, 16 or 20 spins for respectively 8, 10 and 12 boxes). A final score is calculated as the proportion of stickers found to the total number of spins required to find all stickers

Conflict scale (cognitive flexibility; Zelazo, 2006). This task consists of four levels of increasing difficulty (Categorization/Reverse Categorization, Dimensional Change Card Sort (DCCS)–Separated, DCCS–Integrated, and DCCS–Advanced), and children begin the task at the appropriate level for their age. Children are asked to categorize items, either plastic animals or cards, according to a rule, and if they succeed on 5 trials out of 6, the rule is changed. For example, children are instructed to sort cards according to color (red or blue). Then, the experimenter announces that they will stop playing the "color game" and now play the "shape game". Children must then sort cards according to shape (star or truck). There are 12 trials per level, for a maximum of 48 points.

Shape Stroop (inhibition; Carlson, 2005; Kochanska, Murray, & Harlan, 2000). First, children are shown six cards depicting three fruits (three large and three small fruits). Children are asked to identify each fruit (e.g., "Show me the big apple"). Then, children are shown three cards, each depicting a small fruit embedded in a large fruit, and ask to point to each small fruit. A score out of three possible point is calculated.

Statistical Analyses

All analyses were conducted using IBM SPSS Statistic Version 21 (SPSS Inc., Chicago, IL). Independent sample *t* tests were conducted for all continuous variables and chi-square (X^2) tests were conducted for all categorical variables. To be considered different, the group difference has to have a *p*-value of $< .05$ on the outcome variables. Additionally, effect sizes were calculated using Cohen's *d* for continuous data and Cramer's *V* for categorical data. Available-case analyses were performed, such that sample sizes ranged between 58 and 72 for the OI, and between 64 and 84 for the CC. Data were missing when the parents did not complete the questionnaire booklet, the cognitive assessment could not be performed due to lack of cooperation, or when participants from the OI group dropped out before the six-month post-injury time point.

Results

As displayed in Table 1, the OI and CC groups did not differ in terms of their age at assessment, socioeconomic status, parental education, gender, handedness, language or ethnicity.

In addition, there was no difference between the two groups in terms of developmental and medical history (see Table 2). When presence of medical conditions was considered, only those that were exhibited by at least two participants in the sample were reported. Eye, ear, nose and throat problems, gastrointestinal problems, and pulmonary problems were retained in the analyses, and the frequency was comparable in the two groups.

As can be seen in Table 3, children in the two groups did not differ in behavioral (ABAS and CBCL) or family characteristics (FAD, DAS and PSI), as reported by the primary caregiver. These results were observed when analyzing both pre-injury and post-injury characteristics of the OI group. Only the difference for pre-injury ($p = .08$, $d = 0.29$) and post-injury ($p = .05$, $d = 0.33$) ABAS scores on the Conceptual scale approached statistical significance, and effect sizes were small. Since the ABAS Conceptual scale approached statistical significance, we verified the sub-scores and no significant group differences were found for the Communication, Functional Academics or Self-Direction subscales ($p > .05$). Besides, no group differences were found on any of the CBCL subscales and total scores.

Finally, cognitive measures and PCS ratings were obtained six-month post-injury for the OI, whereas they were obtained immediately after recruitment for the CC (see Table 4). As expected, neither group reported elevated post-concussive symptoms and no group differences were found, whether in the last week or the past six months. When the OI and CC were compared in terms of their cognitive performance, they did not differ in terms of general intellectual functioning, verbal abilities, executive functions or theory of mind.

Discussion

The aim of this study was to directly compare community (CC, or "typically developing") and orthopedic controls (OI) aged between 18 and 60 months on a range of variables relevant to early development and to pediatric TBI research. Contrary to the formulated hypothesis, the two groups did not differ on any variable tested, indicating similar demographic profiles (age, education, SES, gender, language, ethnicity, handedness), development (birth weight, Apgar, age at first words and first steps), medical history (pregnancy characteristics, birth disorders, medical problems, medication), behavior (internalizing and externalizing problems), adaptive functioning, family factors (family functioning, parental stress, relationship adjustment), concussion-like symptoms (PCSI), cognition (IQ, verbal abilities, executive functioning) and social cognition (theory of mind). The results align with those of Mathias and colleagues who also compared these two types of control groups in a sample of adults between 18 and 79 years and found similarities between them across demographic (age, education, SES, gender), medical (medication use, medical diagnoses), psychosocial (fatigue, pain, depression, social support, concussion-like symptoms, community integration), and cognitive (IQ, motor and information processing speed, memory, verbal fluency, test effort) factors (Mathias et al., 2013). To our knowledge, the current study is the first to compare these control groups on pre-morbid functioning ratings and to conduct comparisons directly between OI and CC in children. Despite the numerous comparisons, no statistically significant group difference was found, and between-group effect sizes were small across all measures. Only pre-injury and post-injury measures of conceptual adaptive behavior (ABAS), which refers to communication, functional academics and self-direction skills, approached statistical significance. Taken together, our results suggest no meaningful differences between OI and CC groups in a group of children aged between 18 and 60 months.

The findings of the current study further call into question the putative advantages of orthopedic versus community control groups. Because this study included some pre-injury questionnaires in the OI group, it is novel in suggesting that, contrary to the stated higher pre-morbid risk factors for sustaining injury in the OI group (Asarnow et al., 1995; Gerring et al., 1998; McKinlay et al., 2010), CCs and OIs start off with similar behavioral and adaptive functioning and do not differ on a range of demographic and developmental indicators that have potential relevance to the study of pediatric TBI. The data also suggest that despite experiencing trauma-related medical consultation and follow-up, the two groups do not differ on symptom outcome, behavior, adaptive functionning, family functioning, cognition or social cognition six months after the orthopedic injury. Given the comparability of OI and CCs, future TBI research could benefit from important cost savings and ease of recruitment by using CCs. Nevertheless, our understanding of injury mechanisms is still in its early stages and recent work suggests that concomitant peripheral injuries can modify the outcomes and the pathobiology of TBI (McDonald, Sun, Agoston, & Shultz, 2016). A comparison group of orthopedically injured individuals might help to control for these mechanisms that are not well understood at the moment.

Despite supporting the findings of Mathias and colleagues in adults, the results of this study should be construed in light of the particularities of the developmental period studied and caution should be exercised in generalizing the comparability of the two control groups to older pediatric stages (Mathias et al., 2013). Our sample consisted of preschoolers, aged between 18 and 60 months and, as the youngest members of society, preschoolers present the shortest developmental histories and as such little is known of their exact cognitive, social and behavioral make-up. Children with known developmental, psychological, neurological or other medical pathophysiology were excluded from the study, but it is possible that some individuals will go on to develop or be diagnosed with conditions (e.g., attention deficit hyperactivity disorder, learning disabilities, language delay) at older ages and this may later affect the comparability of the two groups. Moreover, there is evidence that children with developmental disability are more likely to sustain injury (Lee, Harrington, Chang, & Connors, 2008). Future studies in older children and adolescents should verify whether the findings of this study extend upward through development and should carefully monitor the occurrence of developmental disabilities in populations of interest.

The data should also be interpreted alongside study limitations. Although the outcomes assessed are numerous and present a wide range of domains of functioning, they are limited to those included in the larger prospective study, and as such do not constitute a complete neuropsychological or psychosocial assessment. In addition, outcome was only evaluated at 6-months post injury (for the OI group) and therefore does not preclude the possibility that the two groups may have differed on outcome at more acute stages given the possible impact of pain, fatigue, post-traumatic stress, and other medical interventions in the OI group in the shorter term (acute – 3 months). Attention, processing speed, reaction time, perceptual skills and motor abilities may all be relevant to pediatric TBI populations and functioning in these domains should be compared in future studies. Given the young age of the participants, other individual and family variables may also be of interest, such as temperament in young children and psychological factors (e.g., anxiety and depression) in their parents. Finally, the participants in the study were compared on a measure of post-concussive symptoms given the high relevance of such a measure to studies of mTBI; however, there is currently no validated PCS questionnaire for infants, toddlers or preschoolers. In the absence of any other measure, we used the PCS-I (Mittenberg et al., 1997), commonly used in older children and adolescence and validated for youth 5 to 18 years of age. Future work developing and applying more developmentally appropriate scales of PCS in young children may reveal alternate findings.

Conclusions

Preschool children (i.e., 18–60 months of age) with orthopedic injuries present with comparable demographic, developmental, medical and pre-morbid behavioral and adaptive profiles as control children recruited from community settings. They are also comparable on measures of adaptive functioning, behavior, family functioning, concussive-like symptoms, global cognition, executive functioning, and social cognition (theory of mind) when tested six months after injury. The findings are applicable to studies seeking to identify appropriate control groups in the context of pediatric TBI research and suggest no clear advantage of community versus injured controls in the youngest developmental age group, though further work should verify this conclusion in other domains of functioning, at more acute assessment time points, and in older children. Also, the true comparability of the two control groups should be tested with respect to clinical groups of children with TBI across the range of severities and with respect to other cognitive outcome variables relevant to TBI research, such as attention, reaction time, working memory.

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Table 1

Demographic characteristics

	OI	CC					
	M (SD)	*M(SD)*	Difference	95% CI	*t*	*p*	*d*
Age at assessment, months	40.98 (11.20)	43.29 (11.65)	-2.09	-5.91 to 1.73	-1.09	.28	0.18
SES	57.75 (13.65)	59.37 (12.07)	-1.62	-5.78 to 2.55	-0.77	.44	0.13
Parental education	3.03 (1.02)	2.85 (0.82)	0.18	-0.11 to 0.47	1.22	.23	0.19
	N *(%)*	N *(%)*			X^2	*p*	*V*
Gender [male]	34 (52.8)	43 (48.8)	-	-	0.24	.62	0.04
Handedness [right-handed]	47 (78.3)	62 (78.5)	-	-	2.17	.54	0.13
Language at assessment [French]	59 (96.7)	84 (100.0)	-	-	2.79	.10	0.14
Ethnicity [Caucasian]	54 (78.3)	66 (80.5)	-	-	3.36	.50	0.15

Note. CC = Community Controls; CI = Confidence Interval; OI = Orthopedic Injuries; SES = socioeconomic status.

Table 2

Developmental and medical history

	OI	CC					
	M (SD)	*M (SD)*	Difference	95% CI	*t*	*p*	*d*
Birth weight	3377.60 (609.40)	3498.27 (639.07)	-120.67	-326.37 to 85.03	-1.16	.25	0.19
Birth length	49.82 (6.30)	50.08 (7.85)	-0.26	-2.70 to 2.19	-0.21	.84	0.04
Apgar #1	8.42 (1.22)	8.46 (1.29)	-0.03	-0.47 to 0.40	-1.16	.88	0.03
Apgar #2	9.06 (1.16)	9.02 (1.03)	0.05	-0.34 to 0.44	0.25	.80	0.04
Age at first words	11.20 (3.97)	11.23 (3.22)	-0.03	-1.23 to 1.17	-0.04	.97	0.01
Age at first steps	12.59 (2.37)	12.12 (4.66)	-0.52	-1.75 to 0.70	-0.84	.40	0.14
	N *(%)*	N *(%)*			X^2	*p*	*V*
Pregnancy – smoking	3 (4.2)	2 (2.5)	-	-	0.37	.55	0.05
Pregnancy – drinking	2 (2.9)	5 (6.1)	-	-	0.90	.34	0.08
Pregnancy complications [a]	28 (39.4)	22 (26.8)	-	-	2.75	.10	0.13
Birth complications [b]	17 (23.9)	13 (16.0)	-	-	1.49	.22	0.10
Birth disorders [c]	22 (31.0)	20 (24.7)	-	-	0.75	.39	0.07
Eye, ear, nose, throat problems	16 (22.5)	11 (13.4)	-	-	2.18	.14	0.12
Gastrointestinal problems	3 (4.2)	2 (2.4)	-	-	0.38	.54	0.05
Pulmonary problems	3 (4.2)	4 (4.9)	-	-	0.04	.85	0.02
Currently taking medication	1 (1.4)	4 (5.0)	-	-	1.50	.20	0.10

Note. CC = Community Controls; CI = Confidence Interval; OI = Orthopedic Injuries.
[a.] Pregnancy complication include gestational diabetes, preeclampsia, bleeding, placental abruption, placenta previa, anemia, Rh incompatibility and infection; [b.] Birth complication include abnormal presentation, prolonged labor, umbilical cord compression, caesarean and assisted birth with forceps or ventuouse; [c.] Birth disorders include jaundice, cyanosis, fœtal distress, breathing difficulties and hypoglycemia.

Table 3

Behavioral and family characteristics

	OI	CC					
	M (SD)	*M (SD)*	Difference	95% CI	*t*	*p*	*d*
Behavior							
Pre-injury ABAS-GAC	102.63 (12.85)	98.41 (11.84)	-1.72	-5.67 to 2.22	-0.86	.39	0.14
Post-injury ABAS-GAC	96.51 (11.49)		-1.90	-5.83 to 2.03	-0.96	.34	0.16
Pre-injury ABAS-Social	102.63 (14.01)	104.07 (16.04)	-1.44	-6.29 to 3.41	-0.59	.56	0.10
Post-injury ABAS-Social	104.18 (13.59)		0.11	-4.95 to 5.17	0.04	.97	0.01
Pre-injury ABAS-Practical	91.08 (13.83)	91.60 (13.48)	-0.51	-4.88 to 3.86	-0.23	.82	0.04
Post-injury ABAS-Practical	90.92 (12.46)		-0.68	-5.07 to 3.71	-0.31	.76	0.05
Pre-injury ABAS-Conceptual	97.55 (12.37)	100.73 (9.76)	-3.18	-6.72 to 0.36	-1.77	.08	0.29
Post-injury ABAS-Conceptual	97.22 (11.67)		-3.51	-7.01 to 0.05	-1.95	.05	0.33
Pre-injury CBCL[a] -Internalizing	45.89 (10.07)	47.19 (10.93)	-1.30	-4.67 to 2.06	-0.77	.45	0.12
Post-injury CBCL-Internalizing	48.44 (10.06)		1.25	-0.27 to 4.77	0.70	.48	0.12
Pre-injury CBCL-Externalizing	47.94 (9.38)	48.71 (9.87)	0.77	-3.85 to 2.31	-0.49	.62	0.08
Post-injury CBCL-Externalizing	50.00 (9.25)		1.29	-1.91 to 4.49	0.80	.43	0.13
Family characteristics							
Pre-injury FAD	1.63 (0.45)	1.56 (0.40)	0.07	-0.06 to 0.21	1.06	.29	0.17
Post-injury FAD	1.67 (0.48)		0.11	-0.03 to 0.26	1.48	.14	0.26
Pre-injury DAS	3.90 (0.92)	4.11 (0.88)	-0.22	-0.51 to 0.08	-1.46	.15	0.24
Post-injury DAS	4.03 (0.74)		-0.08	-0.36 to 0.19	-0.59	.56	0.10
Pre-injury PSI-PD	1.98 (0.65)	2.08 (0.66)	-0.10	-0.31 to 0.11	-0.92	.36	0.13
Post-injury PSI-PD	1.96 (0.69)		-0.12	-0.34 to 0.10	-1.05	.30	0.18
Pre-injury PSI-PCDI	1.47 (0.37)	1.45 (0.42)	0.02	-0.11 to 0.15	0.31	.76	0.05
Post-injury PSI-PCDI	1.53 (0.43)		0.08	-0.07 to 0.22	1.07	.29	0.18

Note. ABAS-GAC = Adaptive Behavior Assessment System-Global Adaptive Composite; CBCL = Child Behavior Checklist; CC = Community Controls; CI = Confidence Interval; DAS = Dyadic Adjustment Scale; FAD = Family Assessment Device; OI = Orthopedic Injuries; PSI-PD = Parenting stress index-parental distress; PSI-PCDI = Parenting stress index-Parent Child Dysfunction Interaction.
[a] CBCL *t* scores are reported. T scores above 65 are considered “borderline”, and T scores above 70 are in the “clinical range”.

Table 4

Post-concussive and cognitive outcomes

	OI	CC					
	M (SD)	*M (SD)*	Difference	95% CI	*t*	*p*	*d*
Post-concussive symptoms							
PCS-I - last week [a]	0.67 (1.08)	0.69 (1.28)	-0.02	-0.42 to 0.38	-0.10	.92	0.02
PCS-I - last 6 months	0.95 (1.59)	0.63 (1.53)	0.32	-0.21 to 0.85	1.21	.23	0.21
Global cognition							
Intellectual functioning (percentile)	59.53 (23.61)	60.68 (24.79)	-1.15	-9.27 to 6.98	-0.28	.78	0.05
Verbal abilities (percentile)	55.88 (27.07)	56.00 (25.73)	-0.12	-9.02 to 8.77	-0.03	.98	0.00
Theory of mind							
False belief task	0.76 (0.74)	0.85 (0.73)	-0.09	-0.36 to 0.17	-0.70	.49	0.13
Desires task	5.30 (0.97)	5.45 (0.85)	-1.15	-0.52 to 0.23	-0.78	.44	0.17
Discrepant desires task	2.17 (1.62)	2.14 (1.46)	0.02	-0.97 to 1.02	0.05	.96	0.02
Executive functioning							
Tower of Hanoi	2.25 (1.88)	2.10 (1.49)	0.15	-0.58 to 0.88	0.41	.69	0.09
Delay of gratification	4.61 (3.09)	4.81 (2.85)	-0.20	-1.23 to 0.82	-0.39	.70	0.07
Spin the Pots	0.70 (0.21)	0.71 (0.18)	-0.02	-0.08 to 0.05	-0.50	.62	0.09
Conflict Scale	28.93 (17.07)	30.89 (16.11)	-1.94	-7.74 to 3.86	-0.66	.51	0.12
Shape Stroop	2.45 (0.98)	2.57 (0.77)	-0.13	-0.42 to 0.17	-0.85	.40	0.15

Note. CC = Community Controls; CI = Confidence Interval; OI = Orthopedic Injuries.