UNIVERSITÉ DU QUÉBEC

MÉMOIRE PRÉSENTÉ À

L'UNIVERSITÉ DU QUÉBEC À TROIS-RIVIÈRES

COMME EXIGENCE PARTIELLE

DE LA MAÎTRISE EN SCIENCES DE L'ACTIVITÉ PHYSIQUE

PAR

SARAH IMHOFF

EFFETS D'UN ENTRAÎNEMENT CHEZ DES INDIVIDUS AYANT SUBI UN TRAUMATISME CRANIOCÉRÉBRAL

DÉCEMBRE 2015

UNIVERSITÉ DU QUÉBEC À TROIS-RIVIÈRES

MAÎTRISE EN SCIENCES DE L'ACTIVITÉ PHYSIQUE

Ce mémoire a été dirigé par :

Philippe Fait, Ph.D., ATC, CAT(C).	Université du Québec à Trois-Rivières
Directeur de recherche, grade	Rattachement institutionnel
Normand Teasdale, Ph.D.	Université Laval
Codirecteur de recherche, grade	Rattachement institutionnel

Jury d'évaluation du mémoire :

Philippe Fait, Ph.D., ATC, CAT(C).	Université du Québec à Trois-Rivières
Prénom et nom, grade	Rattachement institutionnel
Isabelle Gagnon, Ph.D., Pht.	McGill University
Prénom et nom, grade	Rattachement institutionnel
Émilie Lachance, Ph.D.	Université du Québec à Trois-Rivières
Prénom et nom, grade	Rattachement institutionnel

REMERCIEMENTS

Ayant moi-même subi deux traumatismes craniocérébraux légers (TCCL) lors de mes études, j'ai développé un intérêt envers cette problématique. J'ai ainsi découvert un sujet passionnant et des possibilités de recherches non explorées. C'est avec enthousiasme et passion que j'ai poursuivi des études de deuxième cycle avec Philippe. C'est donc sans surprise que mes premiers remerciements sont dirigés vers Phil qui a su me donner des défis à ma portée et me sortir de ma zone de confort! Phil, je tiens à te remercier pour les opportunités et pour les encouragements! Tu m'as donné la piqure et j'ai très hâte de poursuivre au doctorat avec toi! Merci x 1000! Jean-Daniel, une chance que tu es là! Merci pour toute l'aide que tu m'as apportée au cours de ma maîtrise et pour ton amitié! J'aimerais aussi remercier Normand, Martin et Mathieu qui m'ont apporté une aide précieuse lors des projets de conduite automobile. Un merci particulier à Mathieu pour ta patience/support technique 101! Je tiens à remercier les professionnels de la *Clinique Cortex, Médecine et Réadaptation* et de la *Clinique Neuropsychologique* pour leur support et pour leur implication dans mon projet de maitrise. Finalement, merci à Mom, tu as toujours raison! Merci pour tout, bisou! Je tiens à souligner l'appui d'Adam, mon amoureux, pour ton support moral et les nombreux cafés qui sont toujours meilleurs quand c'est toi qui les fait!

SOMMAIRE

Les connaissances scientifiques sont peu élaborées quant au traitement et au diagnostic du traumatisme craniocérébral (TCC), et ce, particulièrement lorsque la récupération perdure au-delà de la période initiale de redressement attendu. Il est impératif d'améliorer les lignes directrices pour permettre aux professionnels d'agir de façon efficace et uniforme envers les patients ayant subi un TCC. Ce mémoire de maîtrise propose de combler les lacunes dans la littérature relativement à l'entraînement et la récupération chez deux populations distinctes surreprésentées dans la population ayant subi un TCC soit : 1) les enfants et adolescents ayant un rétablissement atypique à la suite d'un TCC léger (TCCL) et; 2) les individus adultes ayant subi un TCC et échoué leur évaluation de conduite sur route. Ce mémoire est présenté sous forme de trois articles scientifiques. Une vue d'ensemble de la problématique est présentée dans le chapitre 1. Une courte introduction spécifique à la population pédiatrique ainsi que le premier article *Efficiency of an active rehabilitation intervention in a pediatric population with atypical recovery following a mild traumatic brain injury* font l'objet du chapitre 2. L'objectif de cette étude est d'identifier si l'ajout d'un programme d'activité physique améliore la récupération des enfants et adolescents âgés de 10 à 17 ans qui récupèrent de manière atypique suivant un TCCL. Pour ce faire, 15 participants âgés de 15,00 ± 1,69 ans ont reçu les soins standards en plus d'une intervention en réadaptation active. Tous les participants ont rapporté avoir récupéré pleinement suivant l'intervention en réadaptation active. L'article 2 *Driving assessment and rehabilitation using a driving simulator in individuals with traumatic brain injury: a scoping review* et l'article 3 *Training driving ability in traumatic brain injured individual using a driving simulator: A case report* sont

présentés dans le chapitre 3. Nous avons cherché à évaluer si un programme de réadaptation sur simulateur de conduite peut améliorer les performances de conduite des individus ayant subi un TCC. Dans ce sens, une revue de littérature et l'étude de cas d'une femme de 20 ans ont permis de démontrer que l'entraînement sur simulateur de conduite automobile représente une avenue thérapeutique intéressante lors de la réadaptation des individus ayant subi un TCC. Il est primordial d'améliorer les connaissances quant à la prise en charge des patients ayant subi un TCC. Ce mémoire de maîtrise démontre que l'entraînement est un élément clé de la réadaptation des sujets ayant subi un TCC. Puisque ces projets sont inspirés des activités cliniques, ceux-ci ont le potentiel d'influencer la pratique des intervenants en traumatologie.

TABLE DES MATIÈRES

REMERCIEMENTS iii

SOMMAIRE iv

LISTE DES TABLEAUX vii

LISTE DES FIGURES viii

LISTE DES ABRÉVIATIONS ix

CHAPITRE 1 1

Introduction générale 1

CHAPITRE 2 7

Efficacité d'une intervention en réadaptation active chez une population pédiatrique ayant une récupération atypique suite à un traumatisme craniocérébral léger 7

Article 1: Efficiency of an active rehabilitation intervention in a pediatric population with atypical recovery following a mild traumatic brain injury 14

CHAPITRE 3 43

Entraînement des capacités à conduire chez des individus ayant subi un traumatisme craniocérébral 43

Article 2: Driving assessment and rehabilitation using a driving simulator in individuals with traumatic brain injury: a scoping review 48

Article 3: Training driving ability in traumatic brain injured individual using a driving simulator - A case report 76

CONCLUSION GÉNÉRALE 94

RÉFÉRENCES 97

LISTE DES TABLEAUX

Tableau 1: Caractéristiques cliniques du TCCL ... 9
Tableau 2: Symptômes communs à la suite d'un TCCL ... 10
Table 3: Participants characteristics ... 25
Table 4: Postconcussion Symptom Inventory results ... 33
Table 5: Neuropsychological results ... 35
Table 6: Coordination and balance ... 36
Tableau 7: Atteinte pouvant limiter la capacité à conduire ... 46
Table 8: Included studies description ... 66

LISTE DES FIGURES

Figure 1: Active Rehabilitation Intervention progression 27
Figure 2: Correlation of duration of the intervention to self-reported adherence 32
Figure 3: Flowchart of inclusions and exclusion of article 58
Figure 4: Speed regulation results 88
Figure 5: Proportion of incorrect lateral positioning's duration 89

LISTE DES ABRÉVIATIONS

GCS: Glasgow Coma Scale

mTBI: Mild traumatic brain injury

PCS: Postconcussion syndrome

SPC: Syndrome postcommotionnel

TBI: Traumatic brain injury

TCC: Traumatisme craniocérébral

TCCL: Traumatisme craniocérébral léger

TCCG: Traumatisme craniocérébral grave

CHAPITRE 1

Introduction générale

Le traumatisme craniocérébral

Définition. Le traumatisme craniocérébral (TCC) est défini comme une blessure structurelle et/ou une perturbation physiologique de la fonction cérébrale induite à la suite d'un traumatisme résultant d'une force externe (accélération, décélération, force rotatoire, etc.). Celui-ci est déterminé par l'apparition d'au moins un des signes/symptômes suivants (Department of Veterans Affairs/Department of Defense, 2009):

1. Diminution de l'état de conscience pouvant aller jusqu'à la perte de conscience;
2. Perte de mémoire des évènements immédiatement avant ou après l'évènement;
3. Altération de l'état mental au moment de l'évènement (confusion, désorientation, étourdissements, etc.);
4. Déficits neurologiques (faiblesse, perte d'équilibre, changements dans la vision, praxis, parésie/hémiplégie, perte de sensation, aphasie, etc.) pouvant être transitoires; et,
5. Lésion intracrânienne.

Le terme TCC inclut toutes les catégories de blessures allant de l'absence d'anomalie visible au cerveau sur l'imagerie médicale (TCC léger) aux hématomes sévères lors des cas graves de lésions cérébrales (World Health Organisation, 2006). L'échelle de Coma de Glasgow (GCS) (Teasdale & Jennett, 1976) permettant d'estimer l'état de conscience d'un individu est l'index le plus souvent utilisé pour classer la sévérité du TCC : léger (13-15), modéré (9-12) et grave (moins de 8). D'autres critères tels, l'amnésie post-traumatique et la perte de conscience ont historiquement été utilisés comme critères de sévérité. Dans sa publication sur les troubles neurologiques, l'Organisme Mondial de la Santé (OMS) (2006) rapporte que 90 % des TCC sont considérés comme atteintes légères alors que 3 à 5 % des cas sont classés dans la catégorie des TCC sévères. Il est important de noter qu'il est possible que la sévérité des symptômes associés au traumatisme puisse ne pas être parfaitement corrélée à la sévérité telle que définie par GCS (Scottish Intercollegiate Guideline Network, 2013). Des évidences cliniques démontrent que le TCC peut altérer de manière significative les fonctions cognitives, le fonctionnement social et la performance physique ce qui interfère avec de nombreuses activités de la vie quotidienne (Canadian Institute for Health Information, 2006; Ponsford et al., 2014). En ce sens, le TCC cause des atteintes fonctionnelles persistantes chez la moitié des individus ayant subi un TCC léger à modéré et chez le trois quart des individus ayant subi un TCC sévère (Canadian Institute for Health Information, 2006; McMillan, Teasdale, & Stewart, 2012; Ponsford et al., 2014; Rutland-Brown, Langlois, Thomas, & Xi, 2006; Selassie et al., 2008; World Health Organisation, 2006).

Symptomatologie. Les symptômes suivant un TCC varient en nombre et en intensité selon l'atteinte du sujet. Ceux-ci sont souvent catégorisés selon quatre domaines soit : (a) physique; (b) émotionnel; (c) cognitif; et (d) les troubles du sommeil. Les symptômes les plus souvent observés seront décrits dans les sections spécifiques des chapitres 2 et 3.

Épidémiologie. Le traumatisme craniocérébral est le type le plus commun de lésions cérébrales. Il est reconnu comme état un problème de santé majeur causant morbidité et mortalité dans les pays industrialisés (Canadian Institute for Health Information, 2006; Corrigan, 2001). L'incidence du TCC est difficile à déterminer puisque les individus qui ressentent peu de symptômes ou pour qui les symptômes sont transitoires suivant un TCC ne consultent généralement pas de professionnels de la santé (Ruff, Iverson, Barth, Bush, & Broshek, 2009). Même si la prévalence de blessure à la tête au Canada est inconnue, des études récentes estiment l'incidence annuelle à 600 par 100 000 habitants pour le TCCL et à 11,4 par 100 000 habitants pour le TCC grave (TCCG) (Canadian Institute for Health Information, 2007). D'avril 2003 à mars 2004, 16 811 hospitalisations consécutives à un TCC ont eu lieu au Canada. De celles-ci, 36 % (n = 5970) furent causées par un accident de la route (Canadian Institute for Health Information, 2006). Les accidents de voiture sont l'une des causes principales de TCC (Brown, Elovic, Kothari, Flanagan, & Kwasnica, 2008; Kelly & Becker, 2001; Rutland-Brown et al., 2006). Au Canada, les jeunes adultes (20-36 ans) sont surreprésentés dans la population ayant subi un TCC des suites d'un accident de voiture qui sont responsable de 51 % (n = 1867) des TCC dans cette population (Canadian Institute for Health Information, 2006; Canadian Medical Association, 2012).

Les individus ayant subi un TCC lors d'une activité sportive expérimentent plus souvent une forme légère du TCC, aussi appelée commotion cérébrale. Ces deux termes sont souvent utilisés de manière interchangeable (McCrory et al., 2013; Ontario Neurotrauma Fondation, 2013). Bien que défini comme étant bénin et transitoire dans 80-90 % des cas (résolution des symptômes en moyenne entre 7 à 10 jours), le TCCL peut induire des symptômes pouvant perdurer dans le temps : le syndrome postcommotionnel (SPC) (OMS CIM-10). Cette problématique suscite de plus en plus l'intérêt des communautés sportives, médicales et scientifiques. Des études récentes suggèrent que les enfants et adolescents sont plus susceptibles d'avoir une récupération prolongée suivant un TCCL (Barlow et al., 2010; McCrory et al., 2013; J. Ponsford et al., 1999). Le chapitre 2 traite plus amplement du TCCL dans cette population.

Problématique

Considérant que le TCC peut interférer avec de nombreuses activités de la vie quotidienne, une intervention en réadaptation est requise lorsque des atteintes fonctionnelles et des symptômes postcommotionnels persistent suivant un TCC (Canadian Institute for Health Information, 2006; Ponsford et al., 2014). La réadaptation postcommotionnelle est un défi pour les professionnels de la santé. Certaines interventions cliniques tels la médication, l'activité physique, la thérapie comportementale, la réadaptation cognitive et l'éducation ont démontré de l'efficacité dans la réadaptation des atteintes fonctionnelles et dans la réduction des symptômes postcommotionnels persistants chez des individus ayant subi un TCC (Cooper et al., 2015; Niemeier, Grafton, & Chilakamarri, 2015). Bien que leur efficacité reste controversée, les interventions cliniques ayant recours à l'entraînement des capacités cognitives ayant pour objectif la restauration de la fonction cognitive ou le développement de compétences fonctionnelles adaptatives démontrent des résultats prometteurs (Cooper et al., 2015; Krasny-Pacini, Chevignard, & Evans, 2014; Rohling, Faust, Beverly, & Demakis, 2009; Tsaousides & Gordon, 2009). Considérant la diversité d'atteintes fonctionnelles et de symptômes postcommotionnel, il est impératif d'élaborer des méthodes de traitement spécifiques aux différentes problématiques rencontrées dans cette population. Est-ce que l'entrainement pourrait palier aux atteintes subies suite à un TCC et améliorer la réadaptation postcommotionnelle?

Ce mémoire de maîtrise propose de combler des lacunes dans la littérature relativement à l'entraînement et la récupération chez deux populations distinctes ayant subi un traumatisme craniocérébral soit : 1) les enfants et adolescents ayant un rétablissement atypique à la suite d'un TCC léger et; 2) les individus adultes ayant subi un TCC et échoué leur évaluation de conduite sur route.

CHAPITRE 2

Efficacité d'une intervention en réadaptation active chez une population pédiatrique ayant une récupération atypique suite à un traumatisme craniocérébral léger

Le traumatisme craniocérébral léger

Le traumatisme craniocérébral léger (TCCL) est le type de TCC le plus commun. Une étude canadienne conduite en 2009 examinant les cas diagnostiqués s'étant présentés à l'hôpital et chez les médecins généralistes en Ontario a estimé l'incidence du TCCL entre 493 à 653 par 100 000 habitants (Cassidy et al., 2004; Ryu, Feinstein, Colantonio, Streiner, & Dawson, 2009). Les termes TCCL et commotion cérébrale réfèrent aux effets neurologiques aigus induits à la suite d'un impact mécanique (exemple accélération, décélération, force rotationnelle, etc.) et peuvent êtres inter changés (Ontario Neurotrauma Fondation, 2013). Les techniques d'imagerie médicale clinique ne permettent habituellement pas de déceler des dommages structuraux, mais des études récentes ont démontré que le TCCL induit une dysfonction fonctionnelle neuronale (Bigler, 2008; Giza & Hovda, 2001). Les caractéristiques cliniques du TCCL ont récemment été révisées lors de la 4e Conférence internationale sur les Commotions dans le Sport de Zurich (McCrory et al., 2013). Celles-ci sont détaillées dans la Tableau 1.

Tableau 1: Caractéristiques cliniques du TCCL

1. Le TCCL peut être causé soit par un coup direct à la tête, au visage, au cou ou ailleurs sur le corps créant une force transmise à la tête.
2. Le TCCL se traduit généralement par l'apparition rapide d'altérations de la fonction neurologique qui se résolvent spontanément peu de temps après leur apparition. Dans certains cas, les signes et symptômes peuvent évoluer pendant quelques minutes voir heures.
3. Le TCCL peut entraîner des changements neurologiques, mais les symptômes cliniques aigus reflètent en grande partie une dysfonction fonctionnelle plutôt qu'une lésion structurale. Ainsi, aucune anomalie n'est habituellement observée sur neuro-imagerie standard.
4. Le TCCL entraîne un ensemble de symptômes cliniques impliquant ou non une perte de conscience. Les symptômes cliniques et cognitifs se résolvent généralement progressivement. Cependant, il est important de noter que dans certains cas, les symptômes peuvent se prolonger.

Adapté de : McCrory P et al. Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. Br J Sports Med 2013; 47: 250-258.

Les symptômes les plus souvent observés à la suite d'un TCCL sont exposés dans le Tableau 2.

Tableau 2: Symptômes communs à la suite d'un TCCL

Physique	**Cognitif**	**Émotionnel/comportemental**	**Troubles du sommeil**
Céphalée/migraine	Se sentir au ralenti	Somnolence	Dormir plus qu'à l'habitude
Nausée	Se sentir dans un brouillard	Fatigue/léthargie	Dormir moins qu'à l'habitude
Vomissement	Perte de mémoire	Irritabilité	Éprouver des difficultés à s'endormir
Dysfonctions visuelles	Diminution de la concentration	Dépression	
Pertes d'équilibre		Anxiété	
Étourdissements			
Vertiges			
Sensibilité à la lumière			
Sensibilité au son			
Acouphène			

Adapté de: Ontario Neurotrauma Foundation. Guideline for Concussion/mTBI and Persistent Symptoms: Second Edition. Septembre 2013

Bien que la majorité des individus adultes ayant subi un TCCL récupèrent spontanément (7 à 10 jours), les lignes directrices restent généralement larges et ne suggèrent pas d'interventions efficaces pour promouvoir la récupération lorsque les symptômes perdurent au-delà de la période de recouvrement attendue (Giza et al., 2013; Halstead & Walter, 2010; McCrory et al., 2013; Ontario Neurotrauma Fondation, 2013; Zemek, Duval, Dematteo, & ... 2014). Des symptômes peuvent persister chez 11 à 17 % des jeunes ayant subi un TCCL (Barlow et al., 2010; Gagnon, Galli, Friedman, Grilli, & Iverson, 2009; McCrory et al., 2013; J. Ponsford et al., 1999). Le syndrome post-commotionnel (SPC) réfère à la persistance de symptômes au-delà de 4 semaines suivant le TCCL (OMS CIM-10). De plus, il semble que si les symptômes perdurent au-delà de la période de récupération attendue, il est peu probable que le patient récupère spontanément sans intervention (Leddy, Baker, Kozlowski, Bisson, & Willer, 2011; Leddy et al., 2010).

L'activité physique : une avenue thérapeutique intéressante?

Très peu de recherches cliniques ont porté sur l'efficacité de l'activité physique comme intervention thérapeutique chez une population lente à se rétablir suite à un TCCL. Des études ont démontré que l'activité physique de type aérobie de faible intensité pouvait contribuer à la réadaptation postcommotionnelle (Baker, Freitas, Leddy, Kozlowski, & Willer, 2012; Griesbach, Hovda, Molteni, Wu, & Gomez-Pinilla, 2004; Leddy et al., 2011; Majerske et al., 2008). Il est démontré que l'activité physique a des effets positifs sur la cognition et la neuroplasticité (Hotting & Roder, 2013; McKee, Daneshvar, Alvarez, & Stein, 2014). De plus, il semble que l'activité physique de type aérobie diminue la dysfonction physiologique causée par le TCCL par la restauration de l'équilibre du système nerveux autonome et par l'amélioration de l'autorégulation de la circulation sanguine cérébrale (Amonette & Mossberg, 2013; Baker et al., 2012; Conder & Conder, 2014). Enfin, l'activité physique pourrait avoir un impact positif sur plusieurs symptômes pouvant se chroniciser suivant un TCCL tels : (a) les troubles de l'humeur; (b); les céphalées; (c) la fatigue; (d) l'anxiété; (e) les troubles de sommeil; (f) les étourdissements; (g) les troubles d'équilibre; et, les atteintes cognitives, etc. (Archer, 2012; Archer, Svensson, & Alricsson, 2012; Baker et al., 2012; Brand et al., 2010; Ensari, Greenlee, Motl, & Petruzzello, 2015; Griesbach, Gomez-Pinilla, & Hovda, 2004; Griesbach, Hovda, et al., 2004; Hotting & Roder, 2013; Larun, Brurberg, Odgaard-

Jensen, & Price, 2015; Leddy et al., 2011; Majerske et al., 2008; Rebar et al., 2015; Rethorst, Wipfli, & Landers, 2009; Rimer et al., 2012; Sady, Vaughan, & Gioia, 2014; Tan, Meehan, Iverson, & Taylor, 2014a; Wise, Hoffman, Powell, Bombardier, & Bell, 2012).

Quelques auteurs ont amorcé des recherches sur l'efficacité de l'intégration d'un programme de réadaptation actif comme intervention thérapeutique. Par contre, le nombre insuffisant d'études, le nombre de sujets restreint de même que la méthodologie utilisée (études de cas série) dans la majorité des articles ne permet pas la justification de l'intégration de ce traitement dans les guides de pratiques. Leddy et al. (2013) ont effectué une étude préliminaire ayant pour objectif de comparer les effets d'une intervention par l'activité physique chez des sujets adultes ayant une récupération atypique à la suite d'un TCC sur les symptômes postcommotionnels et sur le patron d'activation neuronal lors d'une tâche cognitive. Dans cette étude, 4 sujets ayant une récupération atypique suite à un TCCL ont complété un programme de 20 minutes d'activité physique de type aérobie sous-maximale progressif (80 % de la FC atteinte lors d'un test par paliers, protocole de Balke) à raison de six fois par semaine pendant environ 12 semaines. Ceux-ci ont été comparés à 4 sujets sains (contrôles) et 4 sujets ayant une récupération atypique mais participant à un programme d'étirement (placébo). Leddy et al. (2013) ont observé une diminution de l'activité du gyrus cingulaire antérieur, du thalamus et du cervelet chez les sujets ayant subi un TCC. Suite au programme de réadaptation, le patron d'activation neuronal des sujets ayant effectué l'entrainement aérobie était semblable à celui des sujets sains. Finalement, une diminution significative des symptômes postcommotionnels fut observée chez les sujets ayant effectué le programme d'exercices aérobie (Leddy et al., 2013). Des études similaires ont démontré qu'un programme d'exercice pouvait réduire l'importance des symptômes auto rapportés chez les adultes (Leddy et al., 2010) et les enfants et adolescents (Gagnon et al., 2009; Gagnon et al., 2015) chez qui les symptômes persistent suivant un TCC. Ces études ont inspiré le projet de recherche suivant, présenté sous forme d'article.

Dans un souci d'améliorer les connaissances quant à la prise en charge des enfants et adolescents ayant une récupération atypique suite à un TCCL, nous avons étudié l'efficacité de l'intégration d'un programme de réadaptation actif aux soins standards lorsque les participants éprouvent encore des symptômes au repos. Considérant le peu d'ouvrages scientifiques disponibles, nous avons tenté d'intégrer le programme de réadaptation postcommotionnel tel que décrit par Gagnon et al. (2009) aux soins standards du consensus de Zurich (McCrory et al., 2013) pour permettre la comparaison entre les interventions pour une même population. Par contre, notre intervention diffère quant à la fréquence d'entraînement par semaine (3 fois par semaine vs tous les jours) ce qui permettait une progression plus importante de l'intensité du programme d'entraînement aérobie en fin de traitement à l'instar des programmes de réadaptation conduits chez l'adulte.

Article 1: Efficiency of an active rehabilitation intervention in a pediatric population with atypical recovery following a mild traumatic brain injury: A pilot study

IMHOFF Sarah[1,2,3], FAIT Philippe[1,2,3,4], CARRIER-TOUTANT Frédérike[3,5], BOULARD Geneviève[3,5]

1. Département des sciences de l'activité physique, Université du Québec à Trois-Rivières (UQTR), Trois-Rivières, Canada

2. Groupe de recherche sur les affections neuro-musculo-squelettiques, UQTR, Trois-Rivières, Canada

3. Clinique Cortex Médecine et Réadaptation, Québec, Canada

4. Centre de recherche en Neuropsychologie et Cognition (CERNEC), Montréal, Canada

5. Clinique Neuropsychologique, Québec, Canada

Contribution des auteurs

Sarah Imhoff a agi à titre de coordonnatrice de projet. Elle a créé les documents nécessaires à l'élaboration du projet. Elle a effectué la collecte des données d'équilibre, de coordination et de symptômes postcommotionnels et a supervisé le programme de réadaptation. Cette dernière a effectué les analyses statistiques et a analysé les données d'équilibre, de coordination et de symptômes postcommotionnels. Frédérike Carrier-Toutant a effectué la collecte et l'analyse des données neuropsychologique sous la supervision de Geneviève Boulard, Neuropsychologue. Mme Boulard a élaboré l'évaluation en neuropsychologie. Philippe Fait, à titre de directeur, a supervisé la création du projet, l'analyse des résultats et l'écriture de l'article scientifique.

RÉSUMÉ

Introduction. Le traumatisme craniocérébral léger (TCCL) est le type le plus commun de lésion cérébrale et représente un problème de santé majeur chez les enfants et adolescents. Des symptômes d'ordre physique, cognitif et émotionnel de même que des troubles du sommeil peuvent persister chez approximativement 11-17 % des individus ayant subi un TCCL. L'activité physique représente une avenue thérapeutique prometteuse pouvant avoir un impact positif sur la récupération des enfants et adolescents chez qui les symptômes (ex. maux de tête, troubles de l'humeur, anxiété, fatigue, troubles du sommeil, étourdissements, altérations de la fonction cognitive et de l'équilibre, etc.) se chronicisent.

Objectif. L'objectif de cette étude est d'identifier si l'ajout d'un programme d'activité physique améliore la récupération des enfants et adolescents âgés de 10 à 17 ans qui récupèrent de manière atypique suivant un TCCL et qui sont encore symptomatique au repos.

Méthode. Quinze participants âgés de 15,00 ± 1,69 ans ont reçu les soins standards en plus d'une intervention en réadaptation active incluant : (a) un entraînement aérobie progressif en intensité; (b) des exercices de coordination spécifique au sport pratiqué; et, (c) des exercices d'équilibre. Les critères suivants ont été utilisés pour mesurer la résolution des signes et symptômes de TCCL : (a) l'absence de symptômes postcommotionnels pour plus de 7 jours consécutifs; (b) des fonctions cognitives correspondant aux normes lors de l'évaluation par un neuropsychologue; (c) l'absence de déficit lors de l'évaluation de la coordination et de l'équilibre.

Résultats. L'intervention en réadaptation active fut de 49 [Q1 = 27, Q3 = 56] jours. La durée de l'intervention était corrélée à l'adhérence auto rapportée au programme de réadaptation ($\bar{x}$ = 84,64, 19,63 %, r = -0,792, p < 0,001). La fréquence et la sévérité des symptômes auto rapportés ont diminué significativement suite à l'intervention. Le résultat composite du questionnaire de symptômes postcommotionnels a diminué de 36,85 ± 23,21 points à 4,31 ± 5,04 points après l'intervention (Z = -3,18, p = 0,001).

Conclusion. Une intervention en réadaptation active progressive pourrait représenter un atout important lors de la réadaptation des jeunes qui récupèrent de manière atypique suivant un TCCL. Tous les participants ont rapporté avoir récupéré pleinement suivant l'intervention en réadaptation active. De plus amples études comprenant un groupe contrôle sont requises pour valider cette approche prometteuse.

ABSTRACT

Introduction. Mild traumatic brain injury (mTBI) is the most common type of brain injury and represents a major health problem in children and adolescents. Physical, cognitive, emotional symptoms and sleep disorder may persist in approximately 11-17 % of individuals who experienced mTBI. Exercise is a promising therapeutic avenue as it may have a positive impact on children and adolescent who are slow to recover and show mTBI chronic symptoms as: headaches, mood disorder, anxiety, fatigue, sleep disorder, dizziness, impairment of cognitive functions, balance, etc.

Objective. The aim of this study is to identify whether the addition of a personalised *Active Rehabilitation Intervention* to standard care influence recovery of young patients aged from 10 to 17 years old who are slow to recover following mTBI and still symptomatic at rest.

Methods. Fifteen participants aged of 15.00 ± 1.69 years old received standard care and active rehabilitation which includes: 1) low to high intensity aerobic training; 2) specific coordination exercises; and, 3) therapeutic balance exercises. The following criteria were used to measure the resolution of signs and symptoms of mTBI: 1) absence of postconcussion symptoms for more than 7 consecutive days; 2) cognitive function corresponding to standards when assessed by a neuropsychologist; and, 3) absence of deficits in coordination and balance.

Results. The *Active Rehabilitation Intervention* lasted 49 [Q1 = 27, Q3 = 56] days. Duration of the intervention was correlated to self-reported adherence ($\bar{x}$ = 84.64 19.63 %, r = -0.792, $p < 0.001$). Symptoms frequency and severity decreased

significantly after the intervention. Postconcussion symptom inventory (PCSI) score went down from a total of 36.85 ± 23.21 points before the intervention to 4.31 ± 5.04 points after the intervention (Z = -3.18, $p = 0.001$).

Conclusion. A progressive sub-maximal *Active Rehabilitation Intervention* may be an important asset in the recovery in youths who are slow to recover following mTBI. All participants reported full recovery following the *Active Rehabilitation intervention.* Further studies including more participants and a control group are needed to validate this promising new approach.

Introduction

Mild traumatic brain injury (mTBI) or concussion is an acute neurological disorder induced after a direct or indirect mechanical impact (eg. acceleration, deceleration, rotational force, etc.) (McCrory et al., 2013). MTBI is the most common type of brain injury and represents a major health problem in children and adolescents as they are highly represented in sport-related head injury (Canadian Institute for Health Information, 2006; Guerrero, Thurman, & Sniezek, 2000; Selassie et al., 2013; Thurman, 2014). The annual incidence of mTBI in Canadians is estimated at 600 per 100 000 (Cassidy et al., 2004; Ryu et al., 2009). Although recovery following mTBI is usually a short-lived process (7-10 days), physical, cognitive, emotional symptoms and sleep disorder may persist beyond the expected recovery period of three months in 11-17% of mTBI cases in youth (Barlow et al., 2010; Gagnon et al., 2009; McCrory et al., 2013; J. Ponsford et al., 1999). Postconcussion syndrome (PCS) refers to persisting symptoms for more than 1 month following mTBI including headache, nausea, dizziness, fatigue, vision impairment, sensitivity to noise and/or light, balance impairment, difficulty concentrating, memory impairment, drowsiness, anxiety, irritability, feeling "in a fog", among others (WHO ICD-10). Barlow et al. (2010) found that 58.5 % of children aged form 0-18 years old who sustained a mTBI were still symptomatic 1 month following the incident. Whereas children and adolescents presenting postconcussion symptoms beyond 1 month (28 days) following the mTBI are considered slow to recover there is a need to develop feasible and valid interventions to improve recovery in pediatric population who sustained a mTBI.

Scientific knowledge on the treatment of mTBI is poorly developed, especially when postconcussion symptoms persist beyond the normal expected period of convalescence. Up to now, rest have been considered as "the best medicine" after mTBI. Thus, consensus statements either recommend that athletes should rest until they are asymptomatic before introducing physical activity (Giza et al., 2013; Halstead & Walter, 2010; Ontario Neurotrauma Fondation, 2013) or do not stated on how and when should be introduce physical activity when symptoms persist at physical rest over time (McCrory et al., 2013; Zemek et al., 2014). Recent reviews of the literature support the use of exercise as an active rehabilitation treatment when postconcussion symptoms persist beyond the expected recovery period after injury (Schneider et al., 2013; Silverberg & Iverson, 2013) as it may have a positive impact on the following mTBI chronic symptoms: headaches, mood disorder, anxiety, fatigue, sleep disorder, dizziness, impairment of cognitive functions, balance, etc. (Archer, 2012; Archer et al., 2012; Baker et al., 2012; Brand et al., 2010; DeMatteo et al., 2015; Ensari et al., 2015; Griesbach, Gomez-Pinilla, et al., 2004; Griesbach, Hovda, et al., 2004; Hotting & Roder, 2013; Larun et al., 2015; Leddy et al., 2011; Majerske et al., 2008; Rebar et al., 2015; Rethorst et al., 2009; Rimer et al., 2012; Sady et al., 2014; Tan et al., 2014a). Preliminary evidence demonstrated that exercise, when used as a treatment, reduces reported symptoms in adults (Leddy et al., 2013; Leddy et al., 2010) and in youth who are slow to recover after mTBI (Gagnon et al., 2009; Gagnon et al., 2015). In the sake of improving knowledge about the care of youth with atypical recovery following a mild traumatic brain injury, we studied the effectiveness of the integration of an active rehabilitation program with standard care while participants were still experiencing postconcussion symptoms at rest.

Considering the lack of available scientific literature, we tried to integrate the active rehabilitation program as described by Gagnon et al. (2009) to the Zurich Consensus standard care (McCrory et al., 2013) in order to allow comparison between interventions. In contrast, our Active rehabilitation program differs in training frequency per week (3 times a week vs. daily) which allowed a larger increase in the intensity of aerobic training program at the end of treatment such as rehabilitation programs conducted in adults.

Objective. The aim of this study is to identify whether the addition of a personalised *Active Rehabilitation Intervention* to standard care influence recovery of young patients aged from 10 to 17 years old who are slow to recover following mTBI and still symptomatic at rest.

Methods

Participants

Eighteen participants aged from 10 to 17 years old who complained of postconcussion symptoms for more than 4 weeks following a mTBI were referred to the *Active Rehabilitation study* through the *Cortex Medicine and Rehabilitation Concussion Clinic* where they received an interdisciplinary intervention consisting of rest, general education, school adaptations and cessation of participation in physical as proposed by the Zurich Consensus (McCrory et al., 2013) between 2014-04-15 and 2015-02-20. The study was introduced to the families by a registered neuropsychologist during the initial 1 hour meeting in which the interdisciplinary approach presentation and patient interview are completed. Written parental consent and participant assent were completed if both indicated an interest in study participation. The consent form was approved by the Université du Québec à Trois-Rivières (UQTR) ethics review board.

All youth were participating in organized recreational to high performance sport groups for 5.96 ± 3.66 hours per week. Fourteen participants sustained a sport-related mTBI in their principal competitive activity, two had a sport-related mTBI in another recreational sport (alpine skiing fall) and another two had a transport-related incident (bus accident) but were competing in an organized sport setting before the incident. Three participants were not included in the present study, one was not able to complete the final assessment because of a fractured toe and two returned to their sport, against the advice of clinicians, although they were still experiencing postconcussion symptoms. Fifteen children and adolescents (9 females) aged of 15.00 ± 1.69 years were included in this study. Participant characteristics are presented in Table 3. All participants had a normal academic progress and reported no cognitive, behavioral, neurological or musculoskeletal impairments. Participant #4 was treated by carbamazepine (Mylan-Carbamazepine CR) for epilepsy. Participant #6 was diagnosed with influenza and had flu symptoms for 10 days, after being asymptomatic for five days. Participant #7 suffered from iron deficiency anemia, anxiety disorder and had a history of migraines and was treated by iron supplements, almotriptan (Axert®) and amitriptyline (Elavil®). No participants had sustained an mTBI in the previous 6 months before data collection. Seven participants reported amnesia of the event, three had lost consciousness and five had sought medical attention to the emergency department. Participants #3 and #12 had an impact to the head during the study without convincing signs of mTBI. Screening and treatment for associated conditions of cervical (n = 13), oculomotor (n = 10), vestibular (n = 5) and temporo-mandibular (n = 1) dysfunctions were conducted and treated by a registered physiotherapist.

Study design

Participants underwent a symptoms, neurological, balance and coordination assessment before and after the *Active Rehabilitation Intervention*. Initial evaluation was conducted 48 [Q1 = 31 days, Q3 = 86 days] days post mTBI. A standardized mTBI history form was administered by a trained neuropsychologist to obtain detailed information about the mTBI history, including the date of the injury, the description of the accident and the clinical symptoms (loss of consciousness, confusion, amnesia), and the number of auto-reported previous mTBI. Adherence and self-reported state were assessed during a weekly follow-up phone call. Final evaluation was conducted when the participants showed a minimum period of seven days after complete symptoms resolution (9.73 ± 2.12 days). The following criteria were used to measure the resolution of signs and symptoms of mTBI: 1) absence of post-concussive symptoms for more than 7 consecutive days; 2) cognitive function corresponding to standards when assessed by a neuropsychologist; and, 3) absence of deficits in coordination and balance.

Table 3: Participants characteristics

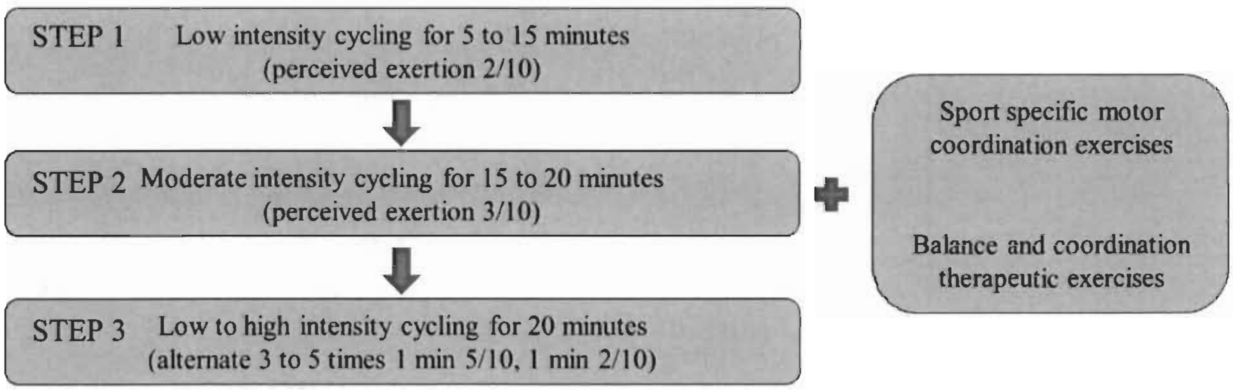
Participants	Age (years)	Sex	Weight (kg)	Height (cm)	Number of previous mTBIs	Amnesia	LOC	Sport	Duration of postconcussion symptoms before the intervention (days)	Active rehabilitation duration (days)	Time without symptoms at post-intervention (days)
01	14.95	F	46.8	160	1	Yes	No	Soccer	60	53	9
02	16.05	F	50.9	163	1	Yes	No	Basketball	86	44	10
03	12.32	M	38.6	156	2	No	No	Hockey*	30	27	13
04	13.60	F	47.7	158	0	Yes	Yes	Gymnastics	30	30	7
05	14.81	M	72.7	178	2	No	No	Hockey	48	49	9
06	15.07	M	75.9	173	1	No	No	Basketball	41	65	7
07	17.54	F	65.0	167	1	Yes	No	Synchronized swimming*	158	53	8
08	14.03	F	61.4	172	0	No	No	Soccer	373	63	9
09	15.77	M	92.3	183	2	Yes	Yes	Football**	120	14	10
10	15.30	F	66.4	171	0	Unclear	No	Basketball	60	24	14
11	11.28	M	36.4	139	2	No	No	Hockey	31	65	8
12	15.38	F	53.6	158	1	No	No	Soccer	30	56	9
13	17.09	M	70.5	166	0	Yes	Yes	Snowboarding	64	23	13
14	14.98	F	54.5	164	0	No	No	Soccer	36	48	10
15	16.76	F	81.8	167	0	Unclear	No	Cycling**	45	49	10

* Transport-related mTBI
** Sport-related mTBI in another recreational sport
LOC: Loss of Consciousness

Active rehabilitation intervention

Since participants could not perform the standard gradual return to physical activities as proposed by the Zurich Consensus (McCrory et al., 2013) because they were still presenting postconcussion symptoms at rest, they were asked to perform a personalized home active rehabilitation program which consists of: 1) progressive submaximal low to high intensity (based on perceived exertion) aerobic training for up to 20 min, 2) low intensity sport specific motor coordination exercises for up to 10 min and 3) balance and coordination therapeutic exercises (Figure 1). The active rehabilitation program was initially performed in clinic under the supervision of a kinesiologist. Participants had to perform the active rehabilitation exercises program 3 times a week at home, school, sport facility or in the clinic. Individual home program was inspired by the Montreal Children's Hospital Trauma Center Mild Traumatic Brain Injury Program (Gagnon et al., 2009; Gagnon et al., 2015) but differed in the frequency of participation per week (3 times a week vs daily) in order to facilitate treatment compliance and minimize the impact on participant's daily life. This also enable a more marked difference in daily participation to exercise allowing better monitoring of symptoms that may be created through exercise and allowed to reach a more intense effort intensity at the end of the treatment. Our Active Rehabilitation Interventionalso differed in intensity and duration of aerobic exercise reached at the end of the program which is similar to rehabilitation programs conducted in adults. Therefore, intensity reached at the end of the program is closer than intensity performed in organized sport groups which could promote a better transition to the sport normally practiced by the participant and may allow a more complete recovery. Patients were informed to limit the duration and intensity of exercises to those prescribed after the clinic evaluation. They were asked to perform their program even if they were symptomatic at rest but had to stop the exercise if any of the symptoms increased by 1 point on a symptom intensity scale from 0 to 10 points or if symptoms increased after exercise participation.

Figure 1: Active Rehabilitation Intervention progression



Aerobic training

Participants were asked to use a stationary bicycle to perform a personalised progressive aerobic training. Because of the difficult access to a bicycle, participant #7 used an elliptic. Level of perceived exertion was monitored using the 10-points Borg category-ratio (CR10) scale where effort is rated from none (0) to maximal (10) (Borg, 1982). This scale was incorporated to the home program in order to help youth monitoring the intensity during exercise. First, participants were asked to perform a symptom dependent low intensity supervised aerobic training session for 5 to 15 minutes. This first session determined the volume of which was initiated the aerobic training progression. In this protocol, participants evolve through three progressive in terms of volume and intensity stages until symptom free: 1) 5 minutes progression every two sessions from 5 to 15 minutes of low intensity aerobic activity (perceived exertion of 2/10), 2) 5 minutes progression every two sessions from 15 to 20 minutes of moderate intensity aerobic activity (perceived exertion of 3/10), 3) 5 minutes low intensity aerobic activity (perceived exertion of 2/10), three to five low to high intensity intervals (alternate 1 minute at high intensity (perceived exertion of 5/10) and 1 minute low intensity aerobic activity (perceived exertion of 2/10)), 5 minutes low intensity aerobic activity (perceived exertion of 2/10). At all stages, the onset or increase of symptoms indicates an immediate halt to the practice of physical activity for a minimum of 24 hours. Patients were asked to return to the previous stage if any of the symptoms increased by 1 point on a 10 points symptoms intensity scale during or after exercise participation. They had to progress through stages if they successfully completed a stage two times in a row. They were instructed not to exercise for two consecutive days.

Sport specific motor coordination exercises

Participants had to perform low intensity sport specific coordination skills (shooting drills, dribbling drills, agility, etc.) for 5 to 10 minutes. The activity had to be stopped if any symptoms were generated.

Therapeutic exercises

Participants were asked to perform three 30 seconds repetitions of three therapeutic exercises consisting of balance exercises. These are displayed in Annex A.

The home program included all three components of the *Active Rehabilitation Intervention* program and was provided to the family in a paper sheet. Progression was monitored through the weekly follow-up phone call. The participants and parents were asked to contact the study coordinator for any question or if symptoms worsen or resolved. Follow-up were conducted until the participant report being symptom free for at least 7 days.

Adherence

Adherence to the *Active Rehabilitation Intervention* was monitored through the weekly follow-up phone call and is define as: "the extent to which a person's behaviour – taking medication, following a diet, and/or executing lifestyle changes, corresponds with agreed recommendations from a health care provider" (Sabaté, 2003). Adherence was determined by comparing participants' report of exercises sessions performed to exercises frequency prescription (%).

Signs and symptoms assessment

Symptoms assessment

Current Postconcussion symptoms and pre-injury symptoms severity were assessed by the Postconcussive Symptom Inventory scale (PCSI) (Sady et al., 2014). PCSI is a validated questionnaire of 21 items rated from 0 to 6 (0 = absence of symptom and 6 = severe problem) for youth of 13 to 18 years old who sustained a mTBI were item 21 is a self-reported abnormality score rated from "0" indicating "No Difference" to "4" indicating "Very Different". The first 20 items were added in order to create the PCSI score (0-120 points). The 18 items PCSI questionnaire form was used for participant younger than 13 years old. Parent were asked to complete the PCSI parent version to rate their children perceived symptom severity. Pre and post intervention PCSI scores and self-reported abnormality scores were compared for each participant, parent and between the participant and their parent. Results of PCSI score for participants #3 and #11 had not been considered in the statistical analysis due to the use of incompatible versions of the questionnaires.

Neuropsychological assessment

A battery of neuropsychological tests was used to assess multiple aspects of cognitive functioning including verbal memory (Rey Auditory Verbal Learning Test (RAVLT) (Schmidt, 1996)), verbal fluency (Delis-Kaplan executive function system (D-KEFS) (Delis, 2001)), working memory (Digit Span from the Weschler Adult Intelligent Scale (WAIS-IV) (Wechsler, 2008) or the Weschler Intelligence Scale for Children (WISC-IV) (Wechsler, 2003)), information processing (Symbol Digit Modality Test (SDMT) (Smith, 1982)) and attention processes (Continuous Performance Test II (CPT-II) (Conners, 2000)). The tests were selected to evaluate the most affected cognitive functions following a mTBI as reported in the literature (Guskiewicz, Ross, & Marshall, 2001; Lundin, de Boussard, Edman, & Borg, 2006). This neuropsychological test battery was administered by a trained neuropsychologist. The test administration was standardized and uniform for all participants.

A psychological inventory (State-Trait Anxiety Inventory (STAI) (Spielberger, 2010)) was also administered to the participant's parents to measure their anxiety about their child condition and their anxiety level as a personal characteristic (Spielberger, 2010).

Coordination and balance

Coordination and balance were assessed by the SCAT 3 Balance examination tests and Coordination examination (McCrory et al., 2013) through the Modified Balance Error Scoring System (BESS) testing, the Tandem gait and the Finger-to-nose task. Participants performed the Modified Clinical Test of Sensory Interaction on Balance (m-CTSIB) (Cohen, Blatchly, & Gombash, 1993) which measure static postural sway and the Limit of Stability test (LOS) which measure dynamic postural control within a normalized sway envelope on a Biodex Biosway™ force platform (Pickerill & Harter, 2011). Finally, balance and coordination were assessed by the Bruininks-Oseretsky Test of Motor Proficiency 2nd Edition (BOT-2) subtests of bilateral coordination, balance and upper-limb coordination (Bruininks & Bruininks, 2005)

(Bruininks & Bruininks, 2005). Subtests total point scores were converted to derived scores in order to have uniform meaning between subtests and participants. Normalized to age and sex scale score were used to statistical analysis.

Statistical analysis

Spearman correlation between the duration of the intervention and self-reported adherence and between *Active Rehabilitation Intervention* duration and time post mTBI pre-intervention were calculated. The Wilcoxon non parametric test for related samples was conducted on every other outcome measures. Outcome measures statistical analyses were conducted with the Statistical Package for the Social Sciences (SPSS) version 22 (SPSS. Inc. Chicago. Illinois. USA).

Results

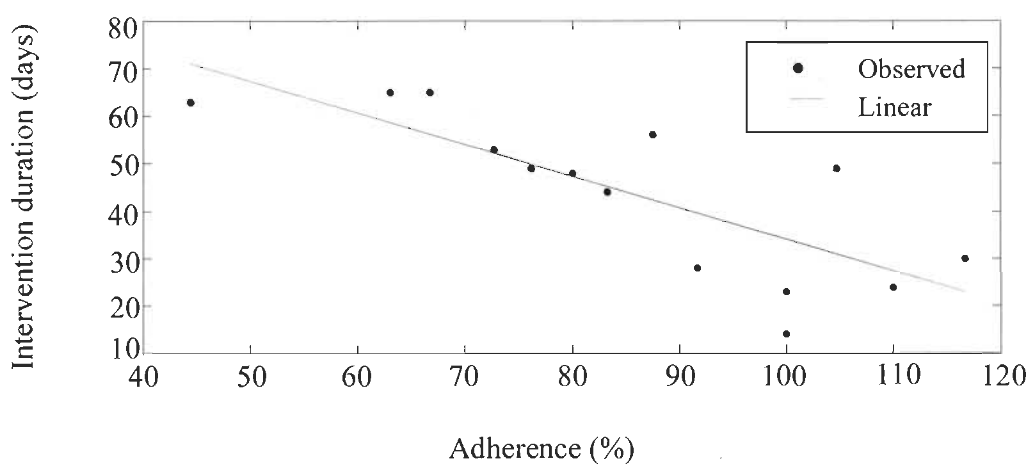
Intervention duration before recovery

Participants were initially evaluated at 48 [Q1 = 31, Q3 = 86] days post mTBI. The intervention lasted 49 [Q1 = 27, Q3 = 56] days before recovery was attained. The final evaluation was conducted after 9 [Q1 = 8, Q3 = 10] days without symptoms (see Table 3). Pearson correlation revealed no correlation between the *Active Rehabilitation Intervention* duration and the duration of postconcussion symptoms before the intervention ($r = -0.120$, $p = 0.671$).

Adherence to the exercise program

Participants performed on average 84.64 ± 19.63 % of the session of the *Active Rehabilitation Intervention*. Duration of the intervention was correlated to self-reported adherence ($r = -0.796$, $p = < 0.001$) (Figure 2). Three participants did the *Active Rehabilitation Intervention* program three to four times a week (every two days) which explained adherence score higher than 100%.

Figure 2: Correlation of duration of the intervention to self-reported adherence



Symptoms

Symptoms frequency and severity decreased significantly after the intervention (see Table 4). Before the intervention, the participants reported 8.90 ± 2.08 symptoms on the PCSI. The number of self-reported symptoms decreased significantly to 1.80 ± 1.44 following the intervention (Z = -3.933, p = < 0.001). The most auto-reported symptoms were fatigue, difficulty concentrating, headache and answering questions more slowly than usual respectively reported by 13, 12, 11 and 11 of the 15 participants. PCSI score went down from a total of 36.85 ± 23.21 points before the intervention to 4.31 ± 5.04 points after the intervention (Z = -3.18, p = 0.001). The self-reported abnormality score (PSCI item 21) decreased significantly from 2.00 ± 3.33 points to 0.17 ± 0.39 points (Z = -2.88, p = 0.004). Parents reported similar decrease in symptoms perception of the PCSI score from 38.75 ± 20.27 to 12.75 ± 9.55 points (Z = -2.904, p = 0.004). They reported an abnormality score (item 21) of 2.09 ± 0.7 and 0.55 ± 0.52 points before and after the intervention respectively (Z = -2.879, p = 0.004). Abnormality scores were similar between participants and their parents (Z = -1.342, p = 0.180).

Table 4: Postconcussion Symptom Inventory results

	Pre-intervention ± SD	Post-intervention ± SD	Z	*p*
PCSI score (sum of 20 items)*	36.85 ± 23.21	4.31 ±5.04	-3.180[b]	0.001
Self-reported abnormality score*	2.00 ± 3.33	0.17 ± 0.39	-2.877[b]	0.004

*Significant statistical difference
SD, Standard deviation
[b] Based on positive ranks

Neuropsychological results

The results of the neuropsychological test assessment are summarized in Table 5. Participants who remained symptomatic for more than one month showed better performance in some parameters of cognitive functions, such as verbal episodic memory, both in total learning (Z = -2.843, p = 0.004) and in immediate recall (Z = -2.68, p = 0.001), in switching semantic verbal fluency (Z = -2.147, p = 0.032), working memory (operational component (backward)) (Z = -2.54, p = 0.011) and made less omission type errors in a task measuring different attention processes (Z = -2.386, p = 0.017) after the *Active Rehabilitation Intervention*. Other neuropsychological subtests did not differ when compared to the initial evaluation. No correlation were found between the *Active Rehabilitation Intervention* duration and the parental anxiety measured by State-Trait Anxiety Inventory (STAI) state anxiety (r = 0.112, p = 0.692) and trait anxiety (r = 0.042, p = 0.881).

Table 5: Neuropsychological results

		Pre-Intervention ± SD	Post-Intervention ± SD	Z	*p*
RAVLT					
	Trials 1 to 5 total*	47.46 ± 6.18	54.38 ± 7.34	-2.843[b]	0.004
	List B interference	4.76 ±1.59	6.23 ± 1.36	-1.736[b]	0.083
	Immediate recall*	9.77 ± 2.20	11.54 ± 1.90	-2.568[b]	0.001
	Delayed recall	10.08 ± 2.66	11.15 ± 2.27	-1.724[b]	0.085
Verbal fluency (words)					
	Phonemic	26.60 ± 7.23	29.60 ± 9.43	-1.449[b]	0.147
	Semantic	37.64 ± 4.24	35.21 ± 4.81	-1.749[c]	0.080
	Semantic switching (Total responses)*	14.50 ± 2.21	11.93 ± 2.62	-2.147[c]	0.032
	Semantic switching (Total switching)	13.64 ± 2.37	11.36 ± 2.41	-1.891[c]	0.059
Digit span					
	Forward	9.14 ± 1.70	9.29 ± 1.49	-0.426[b]	0.670
	Backward*	7.43 ± 1.10	8.64 ± 1.91	-2.537[b]	0.011
SDMT					
	Total	53.43 ± 7.59	56.86 ± 9.53	-1.857[b]	0.063
CPT II					
	Omission*	4.33 ± 3.94	1.18 ± 1.17	-2.386[c]	0.017
	Commission	23.92 ± 10.08	19.81 ± 7.08	-1.532[c]	0.126
	Hit	380.80 ± 56.99	369.48 ± 35.67	-0.533[c]	0.594
	Hit Reaction time	6.10 ± 2.66	4.73 ± 1.24	-1.600[c]	0.110
	Variability	10.04 ± 7.23	6.32 ± 1.61	-0.800[c]	0.424
	Detectability	0.42 ± 0.585	0.52 ± 0.33	-1.512[c]	0.130

*Significant statistical difference
Note: RAVLT, Rey auditory verbal learning test; SDMT, symbol-digit modalities test; CPT, Continuous Performance Task
SD, Standard deviation
[b] Based on negative ranks
[c] Based on positive ranks

Coordination and balance

Coordination and balance results are presented in Table 6. Modified Balance Error Scoring System (BESS) (Figure 3) one leg (Z = -3.068, $p = 0.002$) and tandem (Z = -2.149, $p = 0.032$) stances, Tandem gait (Z = -3.233, $p = 0.001$), and the Finger-to-nose (Z = -3.234, $p = 0.001$) scores improved after the intervention. Modified Clinical Test of Sensory Interaction on Balance (m-CTSIB) (Figure 4) under the conditions: *Eyes opened*

Firm surface (Z = -2.217, p = 0.027), *Eyes opened Foam surface* (Z = -2.309, p = 0.021) and *Eyes closed Foam surface* (Z = -3.068, p = 0.002) were significantly improved. Limit of Stability (LOS) improved from 56.6 ± 13.14 % to 70.8 ± 9.92 (Z = -3.068, p = 0.002). Finally, the Bruininks-Oseretsky Test of Motor Proficiency 2nd Edition (BOT-2) subtests of *bilateral coordination* (Z = -2.673, p = 0.008) and *upper-limb coordination* (Z = -3.121, p = 0.002) improved significantly after the intervention while *balance* subtest remain unchanged (Z = -0.841, p = 0.400).

Table 6: Coordination and balance

		Pre-Intervention ± SD	Post-Intervention ± SD	Z	*P*
SCAT3					
	BESS Double leg stance	0.07 ± 0.26	0.00 ± 0.00	-1.000^{b}	0.317
	BESS One leg stance*	5.20 ± 2.96	1.73 ± 2.63	-3.068^{b}	0.002
	BESS Tandem stance*	2.80 ± 2.48	1.20 ± 2.01	-2.149^{b}	0.032
	Tandem gait*	17.93 ± 7.89	13.21 ± 4.08	-3.233^{b}	0.001
	Finger-to-nose*	3.54 ± 0.55	3.00 ± 0.48	-3.234^{b}	0.001
Biosway					
	mCTSIB Eyes opened Firm surface*	0.53 ± 0.27	0.39 ± 0.17	-2.217^{b}	0.027
	mCTSIB Eyes closed Firm surface	1.12 ± 0.88	0.69 ± 0.21	-1.874^{b}	0.061
	mCTSIB Eyes opened Foam surface*	0.78 ± 0.21	0.67 ± 0.19	-2.309^{b}	0.021
	mCTSIB Eyes closed Foam surface*	2.27 ± 0.60	1.87 ± 0.46	-1.960^{b}	0.050
	LOS*	56.6 ± 13.14	70.8 ± 9.92	-3.068^{c}	0.002
BOT2					
	Bilateral coordination*	12.33 ± 4.69	16.07 ± 4.03	-2.673^{c}	0.008
	Balance	12.07 ± 4.82	13.27 ± 4.43	-0.841^{c}	0.400
	Upper-limb coordination*	13.73 ± 4.08	18.33 ± 4.03	-3.121^{c}	0.002

*Significant statistical difference
SD. Standard deviation
[b] Based on positive ranks
[c] Based on negative ranks

Discussion

The present study investigated the effects of an *Active Rehabilitation Intervention* integrated to standard care (McCrory et al., 2013) on recovery assessed by coordination and balance performance, cognitive function and postconcussion symptom inventory in youth with atypical recovery following mTBI.

Participants demonstrated statistic improvement on the one leg and tandem stances subtests of the Modified Balance Error Scoring System (BESS) test. We observed improvement of the initial tandem gait result (17.93 ± 7.89 sec) to normal performance (<14 sec) after the *Active Rehabilitation Intervention* (13.21 ± 4.08 sec). Every subtests of the Modified Clinical Test of Sensory Interaction on Balance (m-CTSIB) and Limit of Stability (LOS) normalized after the intervention although *mCTSIB Eyes closed Firm surface* did not differ significantly. Finally, Bruininks-Oseretsky Test of Motor Proficiency 2nd Edtion (BOT-2) subtests of *bilateral coordination* and *upper-limb coordination* improved significantly but scale scores range stayed in the *Average* descriptive category as well as the *Balance* subtest. *Balance* subtest results are consistent with those of Gagnon et al. (2015). These results are consisting with the literature indicating that coordination and balance are known to be altered after mTBI in youth and young adults (Guskiewicz, 2003; Guskiewicz & Register-Mihalik, 2011; Guskiewicz et al., 2001; King et al., 2014; Schneiders, Sullivan, Gray, Hammond-Tooke, & McCrory, 2010). Coordination and balance component of the *Active Rehabilitation Intervention* could impact the coordination and balance assessment results under the effect of the practice. Therefore, interpretation of the results must be made cautiously. The results suggests that athletes still presenting postconcussion symptoms for more than 1 month following mTBI showed better performances in some parameters of verbal episodic memory, working memory (operational component), verbal fluency, and attention processes after the *Active Rehabilitation Intervention*. These results are consistent with the literature, indicating that episodic verbal memory, working memory, verbal fluency and attention processes appear to be affected following a mTBI (Guskiewicz et al., 2001; Lundin et al., 2006). Although there is a significant improvement in some parameters of cognitive functions, other parameters remain not statistically significant. This finding may be explained by the fact that athletes initially did not show any cognitive impairment. It may also relate to an incomplete recovery process, although participants report a subjective improvement in terms of number and intensity of auto-reported symptoms. This is consistent with the literature indicating that although in most cases, cognitive recovery largely overlaps with the time course of symptom recovery, cognitive recovery may occasionally follow clinical symptom resolution (Bleiberg et al., 2004; Fait, McFadyen, Swaine, & Cantin, 2009; McCrory et al., 2013). However, the limitations of the study, including small sample size and the use of alternative forms of neuropsychological tests, which could induce a learning effect on the post-test measures, may have reduced the scope of this study.

Since postconcussion symptoms are not specific to mTBI, some patient may report symptoms on PCSI even if they report having recovered from their mTBI (Sady et al., 2014). In this study, participant's self-reported abnormality score normalized after the *Active Rehabilitation Intervention*. Although there is a need to develop reachable and valid interventions to improve recovery in pediatric mTBI population, the literature supports the use of exercise as an active rehabilitation intervention when symptoms persist beyond the expected recovery period after mTBI in adults (Schneider et al., 2013; Silverberg & Iverson, 2013). To date, only two similar studies conducted such intervention in youth thru the Montreal Children's Hospital Trauma Center Mild Traumatic Brain Injury Program (Gagnon et al., 2009; Gagnon et al., 2015). Although our intervention differs in frequency of participation per week and in intensity/duration of aerobic exercise reached at the end of the program, the total duration of the *Active Rehabilitation Intervention* before recovery (44.20 ± 16.56 days) was similar to those observed by Gagnon et al. (2009) of 30.80 ± 18.20 days and by Gagnon et al. (2015) 47.60 ± 32.90 days. Participants of these studies were symptomatic for more than 2 to 3 months on average. All reported a full recovery from mTBI after the intervention. Barlow et al. (2010) reported that *"if a child with mTBI was symptomatic at 100 days, this child would have 40 % likelihood of remaining symptomatic"* and they mentioned that 13.7 % of children older than 6 years old were symptomatic 3 months after the injury. Although the recovery time overlaps thisobserved by Barlow et al. (2010), it is possible that physical activity had promoted recovery post mTBI considering that all participants reported a full recovery and the unlikeliness of spontaneous recovery. Furthermore, the *Active Rehabilitation Intervention* duration was not correlated to duration of auto-reported postconcussion symptoms since the last mTBI ($r = 0.205$, $p = 0.464$). Moreover, there is an apparent dose-response relationship between duration of the intervention and self-reported adherence ($r = -0.792$, $p = < 0.001$). These leave us to believe in the effectiveness of exercise to decrease postconcussion symptoms. The lack of a control group and the limited number of participants does not allow us to draw conclusions against the effectiveness of this intervention. However, it is likely that maintaining physical rest is not optimal when recovery process is longer than expected in youth. No participant reported having a deterioration of their condition following the Active Rehabilitation initiation of the program. Therefore, it is likely that the initiation of physical activity of low intensity, without risk of fall or impact, is safe in young athletes one month following mTBI. Physiotherapy treatment may had an impact on physical postconcussive symptoms. More studies are needed to confirm the effectiveness of this method as a therapeutic core component.

Conclusion

A progressive sub-maximal *Active Rehabilitation Intervention* may be an important asset in the recovery in youths who are slow to recover following mTBI. The majority of coordination and balance assessment tests and some cognitive functions, such as working memory, verbal memory, verbal fluency and attention processes presented a significant improvement following the active rehabilitation intervention. Symptoms resolved in every participant independently of the onset of the *Active Rehabilitation Intervention* in the recovery process. It is unclear how the *Active Rehabilitation Intervention* has influenced these results. Further studies including more participants and a control group are needed to validate this promising new approach. It would be interesting to evaluate the impact of different programs components as aerobic exercise on mTBI recovery process. This project has the potential to influence traumatology practice and may promote sports therapy in mTBI rehabilitation although additional research in this area is needed.

Acknowledgements

Our most sincere thanks to the Cortex Médécine et Réadaptation Concussion Clinic health care professionals who supported this research.

This project is held in a Canadian collective effort in order to improve the care of children and adolescents with mTBI through the Pediatric mTBI Rehabilitation Intervention Study.

Funding

This study was funded by Fonds de recherche du Québec - Santé (FRQS) and the Corporation des Thérapeutes du Sport du Québec research grant.

CHAPITRE 3

Entraînement des capacités à conduire chez des individus ayant subi un traumatisme craniocérébral

Les incidents reliés au transport (véhicule motorisé, vélo, véhicules récréatifs, etc.) sont responsables d'environ 50 % des TCC et ce, principalement chez les jeunes adultes (Canadian Institute for Health Information, 2006; Canadian Medical Association, 2012; Corrigan, Selassie, & Orman, 2010). Suite à un TCC, il est possible que le patient expérimente des symptômes physiques, cognitifs et émotionnels qui entrainent des déficits fonctionnels pouvant affecter les capacités de conduite (Bottari, Lamothe, Gosselin, Gelinas, & Ptito, 2012; Canadian Council of Motor Transport Administrators, 2013; Canadian Institute for Health Information, 2006; Lew, Rosen, Thomander, & Poole, 2009; Ponsford et al., 2014). Au Québec, le permis de conduire une automobile peut être suspendu à la suite d'un TCC. Si c'est le cas, le patient devra effectuer un examen de conduite automobile sur route supervisé par la Société de l'Assurance Automobile du Québec (SAAQ). De 40 à 60 % des survivants ayant subi un TCC reprendront la conduite automobile, de ce nombre, 2/3 des individus le feront sans évaluation médico-légale (Bazarian et al., 1999; Bivona et al., 2012; Canadian Council of Motor Transport Administrators, 2013; Coleman et al., 2002; Fisk, Schneider, & Novack, 1998; Leon-Carrion, Dominguez-Morales, & Martin, 2005; Nalder et al., 2012; Novack et al., 2010; Ponsford et al., 2014; Rapport, Bryer, & Hanks, 2008; Tamietto et al., 2006). Ceci soulève des inquiétudes puisque les individus ayant subi un TCC rapportent des symptômes pouvant affecter les performances de conduite lors de leur retour sur la route (Ponsford et al., 2014). Il est impératif d'élaborer des stratégies sécuritaires lors de la réadaptation à la conduite automobile.

Le TCC et la conduite

La conduite automobile est un privilège synonyme de qualité de vie et d'autonomie. La capacité à conduire une automobile requiert l'habileté du conducteur à gérer, anticiper et répondre aux situations créées par le trafic (Brouwer, Withaar, Tant, & van Zomeren, 2002). Pour se faire, le conducteur doit faire appel à des capacités perceptivo-motrices et fonctionnelles ainsi qu'à des fonctions cognitives de niveau supérieur (Tamietto et al., 2006). Le TCC peut induire des déficits moteurs, cognitifs et comportementaux qui influencent les capacités de conduire un véhicule. Le Tableau 7 présente quelques atteintes ayant un impact sur la capacité d'un individu à conduire de façon sécuritaire un véhicule tel qu'identifié par le Conseil Canadien des Administrateurs en Transport Motorisé. Les individus ayant subi un TCC ne semblent pas être conscients de leurs déficits et croient être aptes à la conduite automobile ce qui est préoccupant lors de la reprise de la conduite automobile dans cette population (Canadian Council of Motor Transport Administrators, 2013; Canadian Medical Association, 2012; Huchler S, 2002; Lundqvist & Alinder, 2007; Lundqvist, Alinder, Modig-Arding, & Samuelsson, 2011; Rapport et al., 2008). Il a été démontré que les individus ayant subi un TCC sont 2 fois plus à risque d'être impliqués à nouveau dans un accident routier (Bivona et al., 2012; Formisano et al., 2005; Leon-Carrion et al., 2005; Neyens & Boyle, 2012; Rapport et al., 2008; Schanke, Rike, Molmen, & Osten, 2008; Schultheis, Matheis, Nead, & DeLuca, 2002).

Tableau 7: Atteinte pouvant limiter la capacité à conduire

Fonctions potentiellement altérées suite à un TCC	Exemple dans le contexte de la conduite automobile
Fonctions cognitives requises pour la conduite automobile	
Attention (divisée, sélective et soutenue)	Identifier les stimuli importants provenant de l'environnement.
Mémoire (court terme, long terme)	Se souvenir de la signification des signes sur les panneaux routiers.
Temps de réaction complexe	Modifier la trajectoire du véhicule en réponse à un évènement sur la route.
Poursuite visuelle et habileté visuospatiale	Connaitre la distance entre le véhicule et un autre objet.
Fonctions exécutives	Effectuer un virage à gauche sur une intersection avec des arrêts obligatoires.
Traitement de l'information visuelle	
Fonctions motrices et sensorielles requises pour la conduite automobile	
Habileté motrice globale, coordination, dextérité, amplitude de mouvement, force, flexibilité	Contrôle du véhicule (virages, freinage, changements de vitesse, etc.)
Temps de réaction	Freiner en réponse à un évènement sur la route.
Acuité, champ visuel, sensibilité aux contrastes, récupération lors d'éblouissement, perception	Distinguer les voitures, lire les panneaux, voir les lumières.
Fonction auditive	

Adaptation de: Canadian Council of Motor Transport Administrators. (2013). Determining Driver Fitness in Canada: Part 1: Administration of Driver Fitness Programs and Part 2: CCMTA Medical Standards for Drivers *CCMTA Reports*(Edition 13), 1-317.

L'entraînement des capacités à conduire sur simulateur de conduite automobile

L'utilisation du simulateur de conduite lors de l'évaluation des capacités à conduire des patients ayant subi un TCC permet d'obtenir des mesures valides permettant d'évaluer la performance de conduite à long terme (Lew et al., 2005). Très peu d'évidences démontrent le transfert de l'amélioration des capacités cognitives aux activités quotidiennes telle la conduite suite à la réadaptation. Ainsi, la prédiction des capacités à conduire à l'aide des différents tests cliniques peut s'avérer invalide lors du transfert de l'habileté vers la situation réelle (Tamietto et al., 2006). Dans ce sens, l'utilisation du simulateur de conduite pourrait représenter une avenue thérapeutique et évaluative intéressante puisqu'elle permet une stimulation cognitive dans un environnement écologiquement compatible pouvant être modulé et où les données peuvent être enregistrées (Lew et al., 2005). De plus, très peu de recherches cliniques ont porté sur l'efficacité de la réadaptation à conduire sur simulateur de conduite automobile. L'article 2 fait état des connaissances sur l'utilisation des simulateurs de conduite automobile lors de l'évaluation et la réadaptation des habiletés de conduire chez les individus ayant subi un TCC. L'article 3 présente le cas d'une femme de 20 ans chez qui un entraînement des habiletés de conduite fut mené sur simulateur de conduite.

Article 2: Driving assessment and rehabilitation using a driving simulator in individuals with traumatic brain injury: a scoping review

IMHOFF Sarah[1,2], LAVALLIÈRE Martin[3,4], TEASDALE Normand[4,5,6], *FAIT Philippe[1,2,7]

[1]Département des sciences de l'activité physique, Université du Québec à Trois-Rivières (UQTR), Trois-Rivières, Canada

[2] Groupe de recherche sur les affections neuro-musculo-squelettiques, UQTR, Trois-Rivières, Canada

[3] Massachusetts Institute of Technology AgeLab, Cambridge, USA

[4] Faculté de Médecine, Département de Kinésiologie, Université Laval, Québec, Canada

[5] Groupe de recherche en analyse du mouvement et ergonomie, Université Laval, Québec, Canada

[6] CHU de Québec – Université Laval, Centre d'excellence sur le vieillissement de Québec, Canada

[7] Centre de recherche en Neuropsychologie et Cognition (CERNEC), Montréal, Canada

Contribution des auteurs

Sarah Imhoff a effectué la revue de littérature et l'écriture de l'article. Martin Lavallière a collaboré étroitement à l'écriture. Ceci sous la supervision de Normand Teasdale (codirecteur) et Philippe Fait (directeur).

RÉSUMÉ

Introduction. En raison de l'hétérogénéité de la lésion pouvant être induite suivant un traumatisme craniocérébral (TCC) et de la complexité de la tâche de conduite, l'évaluation et la réadaptation des habiletés de conduire chez les personnes ayant subi un TCC sont complexes. L'évaluation conventionnelle des habiletés de conduite (sur route et en clinique) n'a pas démontré son efficacité quant à l'évaluation de la performance de conduite des individus ayant subi un TCC.

Objectif. Nous avons cherché à déterminer si les simulateurs de conduite représentent une avenue intéressante pour l'évaluation et la réadaptation des habiletés de conduite chez les individus ayant subi un TCC.

Méthode. Une recherche des articles publiés depuis 2000 ayant comme contenu l'évaluation et la réadaptation des habiletés de conduite à l'aide d'un simulateur de conduite fut effectuée sur les bases de données PubMed, CINAHL et Cochrane entre le 27/02/2014 et le 04/08/2014.

Résultats. Des 488 articles répertoriés, seuls huit articles ayant comme sujet l'évaluation de la conduite à l'aide d'un simulateur et deux traitants de réadaptation sur simulateur de conduite chez les individus ayant subi un TCC ont été retenus.

Conclusion. Les simulateurs de conduite représentent une avenue prometteuse pour l'évaluation et la réadaptation des habiletés de conduite chez les personnes ayant subi un TCC. Ceux-ci permettent le contrôle des stimuli dans un environnement sécuritaire, stimulant et écologiquement valable et offrent la possibilité de mesurer et

d'enregistrer les performances de conduite. Cependant, le nombre insuffisant d'études ne permet pas d'apprécier pleinement l'efficacité de cette méthode.

ABSTRACT

Introduction. Due to the heterogeneity of the lesion following a traumatic brain injury (TBI) and the complexity of the driving task, driving assessment and rehabilitation in TBI individuals is challenging. Conventional driving assessment (on-road and in-clinic evaluations) has failed demonstrating effectiveness to assess fitness to drive in TBI individuals.

Objective. We aimed to determine if driving simulators represent an interesting opportunity in assessing and rehabilitating driving skills in TBI individuals.

Methods. We searched PubMed, CINAHL and Cochrane library databases between 27-02-2014 and 08-04-2014 for articles published since 2000 with the contents of simulator driving assessment and rehabilitation.

Results. Out of 488, only eight articles with the subject of simulator driving assessment and two with the subject of simulator driving rehabilitation in individuals with TBI were reviewed.

Conclusion. Driving simulators represent a promising avenue for the assessment and rehabilitation of driving skills in TBI individuals as it allows control of stimuli in a safe, challenging and ecologically valid environment and offer the opportunity to measure and record driving performance. An insufficient number of studies, however, do not allow to fully appreciate the effectiveness of this method.

Introduction

Traumatic brain injury (TBI) is a considerable public health problem that has the potential of resulting in long-term disability (Canadian Council of Motor Transport Administrators, 2013; Canadian Institute for Health Information, 2006). TBI includes all grade of injury ranging from no visible abnormality to the brain on medical imagery (mild TBI) to dramatic haematomas in severe cases of brain injury (World Health Organisation, 2006). Clinical evidences have shown that TBI can significantly impair multiples areas of physical, cognitive and social functioning (Canadian Institute for Health Information, 2006). It has been shown to interfere with numerous activities of daily living such as domestic chore, work/school participation and driving (Bottari et al., 2012; Canadian Council of Motor Transport Administrators, 2013; Ponsford et al., 2014). Driving is a complex cognitive and perceptual-motor taking place in a complex environment. It requires integration of multiple abilities (Bivona et al., 2012; Bottari et al., 2012; Brouwer et al., 2002; Canadian Council of Motor Transport Administrators, 2013; Canadian Institute for Health Information, 2007; Galski, Bruno, & Ehle, 1992; Hawley, 2001; Lane & Benoit, 2011; Lew et al., 2009; Novack et al., 2006; van Zomeren, Brouwer, & Minderhoud, 1987), particularly operational (basic driving skills as lateral positioning and speed control) and tactical level of control (judgment and anticipation) (Bottari et al., 2012; Lundqvist & Alinder, 2007). Therefore, TBI may affect specific cognitive, motor and sensory functions that have been identified as "needed for driving" by the Canadian Council of Motor Transport Administrators (CCMTA) as: attention, memory, executive functions, processing speed, visual field, reaction time, mood, sleep, etc. in a transient or persistent manner (Canadian Council of Motor Transport Administrators, 2013).

The prerogative of driving is a strong symbol of independence and autonomy (Berger, Rosner, Kark, & Bennett, 2000; Canadian Medical Association, 2012; Rapport et al., 2008). Although the majority of people with a mild TBI resume driving within a short period (Preece, Geffen, & Horswill, 2013), only 40-60 % return to driving after moderate-to-severe TBI within 5 years after the event (Bazarian et al., 1999; Bivona et al., 2012; Canadian Council of Motor Transport Administrators, 2013; Coleman et al., 2002; Fisk et al., 1998; Leon-Carrion et al., 2005; Nalder et al., 2012; Novack et al., 2010; Rapport et al., 2008). Ponsford et al. (2014), examined aspects of daily living that were affected by TBI in 141 individuals with mild-to-severe TBI at 2, 5 and 10 years post injury. More than 50 % resume driving at 2 years and 70 % at 5 to 10 years after the injury, the majority of them did so without professional driving evaluation (Fisk et al., 1998; Leon-Carrion et al., 2005). This raised some concerns since those individuals with moderate-to-severe TBI continued to report neurological complains, cognition impairments, inappropriate social behavior and emotional disorders at ten years post injury (Ponsford et al., 2014). These impairments can certainly compromise fitness to drive and can pose a risk to road safety. This emphasizes the need for effective clinical rehabilitation of driving abilities in this population. Driving simulators could represent an interesting therapeutic avenue because it allows cognitive stimulation in an ecologically compliant environment that can be modulated towards training requirements and provide objective measures that can be recorded to follow longitudinal status of the TBI individual (Lew et al., 2009). The apparent severity of the original event may not correlate with the degree of persisting cognitive dysfunction. People who recover poorly after suffering from a milder form of TBI (10-15 %) (Hartvigsen, Boyle, Cassidy, & Carroll, 2014; Vanderploeg, Curtiss, Luis, & Salazar, 2007; Willer & Leddy, 2006) may require further assessment as they may have persistent deficits and should not drive until medically cleared (Bazarian et al., 1999; Bottari et al., 2012; Canadian Medical Association, 2012; Classen et al., 2009; Hartvigsen et al., 2014; Preece, Horswill, & Geffen, 2010). When compared to healthy drivers implication in a motor vehicle collision was shown to be more than two times greater for TBI drivers up to 9 years post-injury (Bivona et al., 2012; Formisano et al., 2005; Leon-Carrion et al., 2005; Neyens & Boyle, 2012; Rapport et al., 2008; Schanke et al., 2008; Schultheis et al., 2002). Due to the heterogeneity of the lesion following a TBI and the complexity of the driving task, driving assessment and rehabilitation in TBI individuals is challenging. Conventional driving assessments (on-road and in-clinic evaluations) have failed demonstrating effectiveness to assess safe fitness to drive in TBI individuals. Interventions to evaluate fitness to drive after TBI have been reviewed recently by Ortoleva et al. (2012) and by Classen et al. (2009) and in population with chronic conditions by Marino et al. (2013), Lundqvist et al. (2011), and Vrkljan et al. (2011). Several authors support the use of driving simulator as a valid method to assess fitness to drive when compared to an on-road assessment in healthy drivers (Bedard, Parkkari, Weaver, Riendeau, & Dahlquist, 2010; Chan, Pradhan, Pollatsek, Knodler, & Fisher, 2010; de Winter et al., 2009; Mayhew et al., 2011; Shechtman, Classen, Awadzi, & Mann, 2009; Wang et al., 2010). Driving simulators provides the potential to standardize the evaluation in order to obtain discriminant values to identify unfit drivers. Simulated environment offer safety in a near reality environment and offer the possibility to submit the driver to complex and near-crash driving conditions as proposed by certified driver rehabilitation specialists practicing in United States and Canada (Yuen, Brooks, Azuero, & Burik, 2012).

The aim of this article is to review studies that have used driving simulators to assess and rehabilitate driving skills in individuals with TBI.

Methodology

We searched PubMed (via MEDLINE), CINAHL (plus with full text via ESBCO), Cochrane library and SCOPUS (Elsevier) databases between 27-02-2014 and 02-11-2014 for articles published since 2000 with the contents of driving assessment and rehabilitation using the following key words: "assessment", "rehabilitation", "training", "brain injury", "TBI", "driving simulator" and "virtual reality".

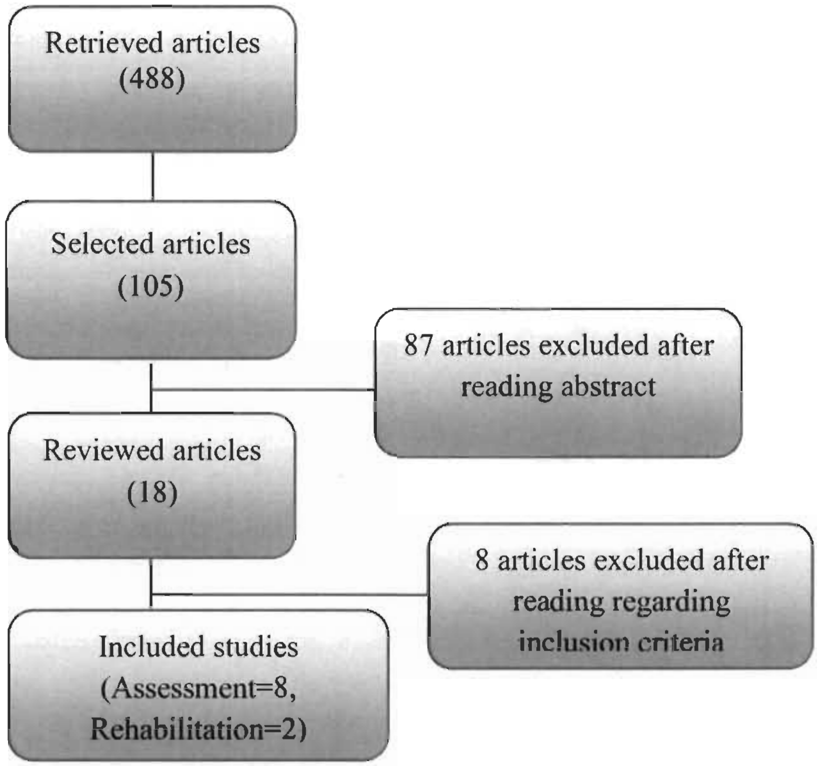
Selection criteria

Articles were selected based upon two principal outcomes: firstly, the assessment of fitness to drive and/or the impact of specific impairments on driving abilities in a driving simulator and secondly, the use of a driving simulator as a driving-specific rehabilitation device after TBI.

Results

The initial search yielded 488 articles (Figure 3). Once collected for analysis, 105 articles were selected based upon their title for further investigation based on the presence of the combination of the key word (brain injury/TBI) and one of the following key word: "assessment", "rehabilitation", "training", "driving simulator" and "virtual reality". Further reading of the abstracts led to excluding 87 articles due to irrelevancy to the present literature review. The main exclusion criteria were: the absence of driving simulator as a device to assess driving skills, the absence of the use of driving simulator in the rehabilitation process and an irrelevance on the nature of the brain injury (non-traumatic injury). Eighteen articles were selected for complete reading. Eight studies were excluded after complete reading because they did not correspond to predetermined selection criteria: review (n = 2), use of virtual reality without a driving task (n = 2), validation of method or theoretical framework (n = 3), irrelevant (n = 1)). Therefore, ten studies satisfied the criteria of the present review. Contents from these studies are summarized in Table 8. To facilitate the presentation of results the following terms will be used: "fitness to drive" will refer to the overall driving performance and "driving skill" will refer to one component of driving performance (for example, lateral control of the vehicle).

Figure 3: Flowchart of inclusions and exclusion of article



Using a driving simulator for assessing driving in TBI individuals

Eight articles with the subject of driving simulator as a device for assessing driving in individuals with TBI were reviewed for this study. Of these, two studies evaluated the effectiveness of the driving simulator to predict overall on-road fitness to drive. The remaining six papers used driving simulators to assess specific driving skills in TBI population.

Using driving simulator to predict on-road fitness to drive

Huchler et al. (2002) studied if driving simulator assessment is a suitable method to predict the outcome ("passed or failed") of an on-road driving evaluation in 33 participants with cerebral damage due to TBI, cerebrovascular disorder or removed brain tumor. Their sample consisted of a population varying from 4 to 448 weeks (mean 45.03 week) post injury. During the in-simulator and the on-road driving, behavior was assessed by a neuropsychologist and a driving teacher (security distance, signaling, filter into a stream of traffic, getting into lanes, speed adjustment, lateral position control, securing, attention to road signs, static and dynamic dangerous traffic situations). The overall fitness to drive was rated on a scale from 1 to 6 (1 representing excellent fitness and score of 5 and 6 an insufficient driving fitness). The outcome of the on-road driving evaluation ("passed or failed") was predicted by the on-simulator driving test with an accuracy of 84.8 %.

Lew et al. (2005) evaluated whether in-simulator assessment and on-road assessment could predict long-term driving performance in 11 individuals with moderate-to-severe TBI. An automatic report of the driving performance was provided after the simulator driving as a Simulator Performance Index (SPI). This report served to evaluate fitness to drive using different variables (speed, speed variability, acceleration variability, speed jerk, red-light violation, lane position error on straight and curved roads, lane position variability, steering jerk, collisions and deviation off-road). Driving performance inventory (DPI) scale enable an external observer to rate driving performance (steering wheel control, throttle and brake pedals control, speed, lane position, breaking reaction time, lane changes, turns, merging into traffic, respect of signs and signals, following distance, safety, decision making, emotional stability) as 2 = Good, 1 = Fair and 0 = Unsafe. This 14-items scale was used by a trained research assistant during the in-simulator evaluation, by the driving program manager who conducted the on-road test and by a parent or sibling of each TBI participant during a 3-hours observation at follow-up to assess long-term fitness to drive. Simulator automated trial outcome significantly correlated with DPI at follow up and demonstrated an overall predictive efficiency of 82 %. Interestingly, the on-road DPI score was not significantly correlated to the in-simulator DPI score, the automated simulator performance index (SPI) or the driving performance at follow-up. Motor vehicle collisions reported at follow-up seemed to tend to a lower score on the automated simulator measures. Thus, the automated simulator performance measure was more sensitive in predicting fitness to drive than on-road observatory rating.

Only two studies used performance in a driving simulator to predict on-road fitness to drive in traumatic brain injured drivers. It remains unclear in what measure in-simulator assessment can predict on-road evaluation outcome. Lew et al. (2005) showed no significance between the in-simulator and the on-road driving assessment while Huchler et al. (2002) demonstrated that the simulator could predict on-road driving assessment outcome with an efficiency of 84.8 %. Results from these studies suggested that in-simulator automated assessment may be as sensitive as on-road observatory rating to predict long term driving performance in TBI individuals.

Using driving simulator to assess specific driving skills

Most of the studies listed for the present article used a driving simulator to assess and compare driving skills between healthy and TBI drivers. Lew et al. (2005) compared TBI driver's automated simulator measures to normative data of 16 healthy controls. They evaluated speed control (speed, speed variability, acceleration, speed jerk, red-light violation) and direction control (lane position, lane position variability, lane position error, steering jerk, deviation, collision). TBI individuals performed four standard deviations (SD) below normative values on general automated simulator measures and on the DPI score. Furthermore, TBI drivers missed significantly more signals on divided-attention task and made more traffic violations than healthy controls.

Schultheis et al. (2006) compared performance at intersections between 15 acquired brain injured (ABI) individuals (10 with moderate-to-severe TBI and 5 who experienced a stroke or a cerebrovascular accident (CVA)) and 9 healthy controls (HC). Driving performance was evaluated at stop sign zones on three intersections (7.6 m before and after each stop sign). Performances at the third stop sign differed slightly between groups. 32 % of HC and 40 % ABI participants did not executed a full stop. Distance from stop sign was respectively of 6.71 m and 8.23 m for the HC and ABI groups. Both groups shorted their mean stop duration of 3.8 sec for the HC group and 2.7 sec for the ABI group. Approaching and departing speed did not differ between groups (HC = approaching: 11.27 km/h and departing: 27.36 km/h, ABI = approaching: 11.27 km/h and departing: 27.36 km/h). Unfortunately, the absence of p values in the results section does not allow to appreciate the significance of the differences presented.

More recently, Milleville-Pennel et al. (2010) used a driving simulator to assess visual exploration in five TBI participants. When compared to healthy controls, TBI participants showed longer eye-fixation durations while driving in a straight section and spent more time in the nearest part of the visual scene to the detriment of the farthest visual zones. While turning, TBI participants spent less time looking to the tangent point zone in benefit of nearer visual exploration zone which may affect trajectory control). Finally, as TBI driver spend more time in nearer visuals zones (trajectory control) they may spend less time for looking to the mirrors, speedometer and environment which can potentially affect anticipation control. The authors attribute these differences in visual search to neuropsychological impairment.

With the aim of describing driving errors in mild TBI and post-traumatic stress disorder (PTSD) population, Classen et al. (2011) compared 18 veterans (13 men, 5 women) diagnosed with mild TBI or PTSD to 20 control participants (6 men, 14 women) on a driving simulator. Driving errors were recorded as vehicle positioning, visual scanning, speed regulation, lane maintenance, signaling, adjustment to stimuli and gap acceptance. Differences in speed regulation (over speeding) in the mild TBI/PTSD group, that may be attributable in part to age and adjustment-to-stimuli, were significantly different compared to control group. Except for signaling that was higher in the control group, other error types were not significantly different between mild TBI and PTSD drivers.

Driving simulators also have been used to establish if driving skills may be affected by TBI specific impairment. Lengenfelder et al. (2002) studied the influence of divided attention on speed control in 3 men who experienced moderate-to-severe TBI compared to control participants (matched for sex, age and education). They designed five driving divided attention conditions: one baseline and four divided attentions condition ranging from simple (numbers presented in the center of the screen) to complex (number presented in random locations) task where the number were presented at 2.4 or 0.6 second intervals. Participants were required to drive and say out loud the number after their appearance on the screen. Compared to control participants, driving speed did not differ in any of the divided attention conditions. As well, the error rate for the secondary task for both the simple and complex conditions did not vary between TBI and control participants.

Lane maintaining is a component of driving performance. Chaumet et al. (2008) investigated how fatigue could affect standard deviation (SD) of the vehicle position from the center of the road in 22 severe TBI individuals during a one hour in-simulator drive when compared to healthy controls (n = 22). Chronic fatigue was assessed using a seven-point Fatigue Severity Scale (score > 32). Participants with TBI had a higher mean fatigue severity score than controls. The SD of the vehicle position was greater for participants with TBI than in control group which indicate poorer vehicle control.

Cyr et al. (2009) investigated the role of divided attention and speed of processing on crash rate in individuals with moderate (n = 2) to severe (n = 15) TBI when compared to healthy controls (n = 16) in high-crash-risk simulated road events. No relationship was found between reaction time and crash rate and between processing speed subtest and divided attention subtest of the UFOV. Reaction time in response to a dual task correlates significantly with crash rate in TBI individuals but not in the control group. TBI individuals didn't differ significantly from healthy controls in terms of dual task performance but crashed significantly more.

Impact of attention impairment and fatigue caused by TBI on driving skills were studies in four studies. Traffic violations seem to be associated with divided attention impairments, when present. Furthermore, even if no significant differences were found in regard of performance to a divided attention test, Cyr et al. (2009) reported a higher crash rate in TBI individuals. Significant impairments were observed in visual exploration and in overall driving performances scores.

Using driving simulator for rehabilitation in individuals with TBI

Only two articles mentioned using driving simulators as an opportunity for rehabilitation of driving skills in individuals with TBI. Cox et al. (2010) aimed to investigate the feasibility of simulator driving rehabilitation training with specific feedback among eleven men from military personal recovering from TBI. Six were randomly assigned to the rehabilitation group and received four to six, 60-90 min individualized rehabilitation training session of driving skills on a driving simulator and residential rehabilitation. In-simulator driving rehabilitation involved alternating between driving in a virtual environment (3 miles of rural, 5 miles of highway and 4 miles of urban driving) and playing a racing game that progressively increase in complexity. Driving skills such as lane positioning, speed control, steering through turns, brake control, dealing with unexpected events, following road rules and follow simulator instruction were assess by an external observer in a composite score. Five controls received residential rehabilitation only. Authors reported that the composite score significantly improved for the rehabilitation group but not in controls. Road rage questionnaire score and Cox assessment of risky driving questionnaire score improved only in the rehabilitation group. No differences were observed for the control group on both questionnaires.

Gamache et al. (2011) published a case study of a 23-years-old woman whose driving licence was revoked after sustaining a severe TBI. The program included 25 training sessions in-simulator over a period of four months. Driving-specific feedback about visual inspection and vehicle control were given before each simulator session. Time to complete the scenario went from 2012 seconds to 1650 seconds at the last session. At 1-year follow-up, she needed 1751 seconds to complete the scenario. According to the authors, this performance was comparable to that of young and healthy drivers of a similar age. At first, the lateral position of the vehicle was deviated to the left (tendency to drive towards the dividing lane) when driving on a straight line and when approaching intersection. Although this tendency decreased with training, it still was present while approaching intersections in the 1-year post-training retention session but SD of the lane position was within normal values. Reaction time to an auditory signal was recorded to assess attentional demand while driving. Mental workload for specific driving contexts decreased significantly with training. For instance, reaction time to the auditory stimuli decreased by more than 100 ms when approaching intersections. No difference was observed in a baseline condition (reaction time without driving). This improvement was maintained at the 1-year follow-up. Speed profiles while approaching intersections also improved. Initially, the profiles were characterized by several breaking periods often followed by accelerations. Through trainings, theses irregularities disappeared and the speed profile was characterized by a single breaking period starting at 5-7 seconds before a complete stop. This normal breaking behavior was retained at the 1-year retention test.

Only two studies aimed to use in-simulator rehabilitation of driving skills in TBI individuals. Studies demonstrated driving skills improvement following in-simulator training. An insufficient number of participants do not allow the generalization of results.

Table 8: Included studies description

Authors	Study objective	Population	Driving simulator	Main outcomes	Assessment/ rehabilitation procedure	Key findings
Assessing driving abilities						
Classen et al.(2011)	Determine differences in driving errors between veterans with mild TBI/PTSD and healthy controls.	Veterans with mild TBI and PTSD (n = 18) (27.00 ± 5.477 years old). Controls (n = 20) (33.70 ±5.75 years old). At the time of testing all participants possessed a valid driver's license or eligibility for a driver's license.	Driving simulator integrated in a 1997 Dodge Neon on a computerized platform with the STISIM Drive Model 500W (Systems Technology, Inc.) with three channel projected images on 0.91 x 1.83 m screens and audio feedback.	-Simulation Sickness Questionnaire -Measured driving errors as: vehicle positioning, lane maintenance, speed regulation, visual scanning, etc.	In-simulator assessment of 15 minutes (simulated road course with 8 intersections).	Combat veterans made more critical driving errors as overspeeding end adjustment-to-stimuli.
Milleville-Pennel et al. (2010)	Assess the visual exploration of TBI individuals while driving.	Males between 35-50 years old with TBI (n = 5) mean of 12 years post-injury (GCS ≤ 8/15).* Controls (n = 6). All drove in regular basis at the time of testing.	Driving simulator software Sim2 (INRETS, MSIS) coupled with a fixed-base driving simulators (gearbox, steering wheel, brake, accelerator and speedometer). Visual scene projected on a 3.02 x 2.28 m screen.	-Neuropsy-chological tests (TAP,WAIS III, D2, Stroop Color Word Test, BADS, TMT) -Eye movement tracking (percentage of time spent in 6 visual zones, duration of eye fixation)	6 progressives laps on a driving simulated environment.	Reduction in the variety and the distance of explored visual zones in individuals with TBI.

*Glasgow Coma Scale (GCS)

Table 1
(*Continued*)

Authors	Study objective	Population	Driving simulator	Main outcomes	Assessment/ rehabilitation procedure	Key findings
Cyr et al. (2009)	Examine the role of impaired divided attention and speed of processing in TBI drivers in reaction to high-crash risk events.	Individuals with TBI (n = 17) most had experienced a severe brain injury (n = 15) mean of 6.3 years post injury (39.5 ± 11.0 years old). Controls (n = 16). At the time of testing all participants held a valid driver's license.	STISIM (Systems Technology, Inc.) drive software that displayed a simulated road-way on a screen which provides a 80 degree field of view and realistic audio effect. Driving simulator include: steering wheel, brake, accelerator, flasher and rear-view mirrors.	-Cognitive testing (UFOV, WAIS-III, WMS-III, NASA-TLX) -Crash rate -Reaction time	20 minutes training session to familiarize participants. 4 scenarios with challenging driving situations.	TBI group crashed significantly more that control group. The crash rate correlates with the dual-task performance.
Chaumet et al. (2008)	Investigate how fatigue affects fitness to drive in TBI individuals.	Individuals who experienced severe TBI (n = 22) between 6 to 12 months post injury. Matched for sex and age controls (n = 22) (33 ± 10 years old).	Real car equipped with Driving simulator three-dimensional software (INRETS, MSIS, Paris, France).	-Sleep and fatigue tests (MWT, FSS, ESS) -Fitness to drive measure by the standard deviation from the center of the road	1 hour session on a virtual reality highway.	Fitness to drive was worse in TBI individuals. Fatigue scores and body mass index can predict driving fitness to drive.

Table 1
(*Continued*)

Authors	Study objective	Population	Driving simulator	Main outcomes	Assessment/ rehabilitation procedure	Key findings
Schultheis et al. (2006)	Examine specific driving performance related to intersections in TBI drivers with virtual reality driving simulator.	Individuals with acquired brain injury (38.8 years old) : moderate to severe TBI (n = 10) and cerebrovascular accident or stroke (n = 5) matched for age and driving experience controls (n = 22). At the time of testing all participants held a valid driver's license.	Steering wheel, gas/break foot pedals (Microsoft Sidewinder), head mounted display Proview™ XL50 Virtual Reality Display headset (Kaiser Electro-Optic, Inc.) and desktop computer.	-Driving performance at stop sign zone (25ft before and after stop sign): full stop, distance from stop, time, approaching and departing speed.	25-35 minutes custom designed simulator course.	Driving performance differ between the two groups. Virtual reality may provide helpful information while examining driving capacity in neurological compromised individuals.
Lew et al. (2005)	Evaluate whether driving simulator and road test evaluation can predict long term fitness to drive.	Individuals with moderate to severe TBI (n = 11) 2 to 25 months post injury (29 ± 12 years old). Controls (n = 16) (36 ± 11 years old). At the time of testing all participants held a valid driver's license.	Systems Technology Incorporated (STI® version 8.16) table-mounted steering wheel, accelerator and brake pedals, speakers and PC monitor.	-In-simulator driving performance: 1) *Simulator Performance Index* (12 in-simulator measured driving parameters) 2) Observational *Driver Performance Inventory*.	Baseline: -In-simulator assessment (3 increasing levels of difficulties road courses), -On-road assessment.	Simulator-based assessment can provide ecological valid measures than may be more sensitive than traditional on- road test to predict long term fitness to drive in TBI individuals.

Table 1
(Continued)

Authors	Study objective	Population	Driving simulator	Main outcomes	Assessment/ rehabilitation procedure	Key findings
Huchler et al. (2002)	Examine whether the driving simulator is a suitable diagnostic and therapeutic device.	33 individuals with brain injury (cerebrovascular disorders, traumatic brain injury or completely removed tumors) with mean period of illness of 45 weeks (45.56 ± 10.81 years old). At the time of testing participants had to own a driving license.	No description available.	-Fitness to drive assessed by a neuropsychologist and a driving teacher (only for the on-road assessment) on a 6 point scale for 10 driving behaviors, -Self-evaluation of fitness to drive.	-90 minutes in-simulator driving session on country road, highway and urban roads, -90 minutes on-road assessment.	The outcome of the on-road assessment (pass or fail) can be predicted by the in-simulator assessment with 84.8% of accuracy.
Lengenfelder et al. (2002)	Investigate the influence of divided attention on driving performance.	3 men who experienced moderate to severe TBI mean 12.67 years post injury (38 ± 3.46 years old). Participants were driving or in process of receiving driving evaluation to reinstate their driving license at time of testing.	PC computer with 21-inch monitor screen equipped with a steering wheel and gas/brake pedals.	-Neuropsychological measure (Auditory Consonant Trigrams, PASAT), Useful Field of View, Driving Divided Attention Task.	-Baseline: driving without the secondary task, -Driving with secondary task (attending to numbers in the driver's visual field) in 4 divided attention condition.	Virtual reality may provide medium for evaluating basic cognitive function and its impact on everyday task.

Table 1
(*Continued*)

Authors	Study objective	Population	Driving simulator	Main outcomes	Assessment/ rehabilitation procedure	Key findings
Rehabilitating driving abilities						
Gamache et al. (2011)	Report the case of a woman who went through an in-simulator training program in order to improve her driving abilities after suffering from a TBI.	Case report of a 23-years-old woman who experienced severe TBI (her driving license was revoked after the accident).	Fixed-based open cab powered by STISIM Drive 2.0 (System Technology Inc., Hawthorn, USA) drive software that displayed a simulated road-way on a screen (1,45 x 2 m) and auditory stimuli.	-Basic simulator data, -Lateral position, -Attentional demands, -Speed profiles.	25 in-simulator training sessions in with specific feedback (58 min). Periodic evaluation with a specific scenario on 12 of the 25 sessions and 1 year long-term retention assessment.	Various comportments of driving were improved by the simulator training. Most of them were consistent at retention test.
Cox et al. (2010)	Investigate the feasibility of simulated driving rehabilitation training.	Military personal recovering from TBI (n = 11). 5 of them were assigned to control group (residential rehabilitation) (21-39 years old). 6 were in the virtual reality driving rehabilitation and residential rehabilitation group (23-31 years old).	Mode T^3 driving simulator which provides 180° field of view with rear and side view mirror image, brake/gas pedal, turn signal, steering wheel and air conditioner.	-Road Rage Questionnaire, -Assessment of Risky Driving Scale, -Driving skills (evaluated by an external observer).	4 to 6, 60-90 minutes rehabilitation sessions of 12 miles course that involve rural, highway and urban driving segments. Pre and post simulator driving assessment.	Driving skills improved significantly in the in-simulator driving rehabilitation group. They also demonstrated diminution in road rage and risky driving questionnaires results.

Discussion

Using driving simulator for driving assessment

Driving simulators have been used with different populations to assess driving skills (Akinwuntan et al., 2005; Akinwuntan, Wachtel, & Rosen, 2012; Cantin, Lavalliere, Simoneau, & Teasdale, 2009; Chan et al., 2010; de Winter et al., 2009; Kotterba, Orth, Eren, Fangerau, & Sindern, 2003; Lavalliere, Laurendeau, Simoneau, & Teasdale, 2011; Lee, Cameron, & Lee, 2003; Marcotte et al., 2008; Mayhew et al., 2011; Reimer, D'Ambrosio, Coughlin, Kafrissen, & Biederman, 2006; Shechtman et al., 2009; Wang et al., 2010). Very little research has been conducted to examine validity of a complete assessment of fitness to drive in TBI population. From all articles reviewed, only two studies have demonstrated effectiveness of driving simulator to assess fitness to drive among TBI population (Huchler S, 2002; Lew et al., 2005). The limited number of studies and the quality of the methodology of some studies make it difficult to draw a clear conclusion. As an example, some studies did not describe the assessment method and the participants' characteristics (for instance, driving habits, number of days post-injury and the severity of the injury). Since recovery possibilities are unknown, it seems important to take into account TBI drivers characteristics when analyzing results from driving assessment. Moreover, when considering driving habits, almost every individual assessed as part of the studies presented in our review held a valid driving license and a lot were driving on a regular basis. This is concerning since almost all studies reported impairments that impact fitness to drive. It is well known that, even in its milder form, TBI can cause long term disability (Canadian Institute for Health Information, 2006, 2007; World Health Organisation, 2006). Therefore, injury severity and time post-injury may affect the type and severity of the impairments. Only one study reviewed for this article assessed individuals with mild TBI (Classen et al., 2011). Their results showed that drivers with mild TBI made more driving errors than healthy drivers.

The use of the on-road assessment as a standard measure is controversial since this evaluation is based on subjective observations in a limited environment and on a short period of time (Amick, Kraft, & McGlinchey, 2013; Canadian Medical Association, 2012; Di Stefano & Macdonald, 2003; Marshall, Man-Son-Hing, Molnar, Hunt, & Finestone, 2005; Scottish Intercollegiate Guideline Network, 2013; Tamietto et al., 2006). Since on-road evaluation is considered as the "gold standard" in most Canadian jurisdictions (Canadian Council of Motor Transport Administrators, 2013; Canadian Medical Association, 2012; Korner-Bitensky, Bitensky, Sofer, Man-Son-Hing, & Gelinas, 2006), the reliability of driving simulator assessment to the on-road testing is of outmost interest. Most studies reviewed did not validate in-simulator assessment with an on-road evaluation. From those who did, Huchler et al. (2002) and Lew et al. (2005) demonstrated the effectiveness of this method to predict on-road fitness to drive in TBI individuals. Moreover, Lew et al. (2005) showed that an automated simulator performance measure related to driving skills was more sensitive in predicting long term fitness to drive that an on-road assessment observatory rating in TBI individuals. Brain injured individuals may compensate their deficit on a short period of time; furthermore, the lack of critical event during the on-road evaluation may falsely indeed assessment success in this population. Driving simulators have shown to be an effective and valid method to predict on-road driving performance (Bedard et al., 2010; de Winter et al., 2009; Mayhew et al., 2011; Reimer et al., 2006; Shechtman et al., 2009; Wang et al.,

2010) and that in-simulator performance may effectively predict collision rate (Hoffman & McDowd, 2010). Kraft et al. (2010) and Schultheis and Rizzo (2001) reviewed parameters that are most relevant in driving simulation literature assessment. Driving simulators offer a promising method for fitness to drive assessment as they can provide challenging driving scenarios and accurate measurements that may help to detect critical driving errors in a secured and ecologically valid environment.

Using driving simulator for driving rehabilitation

Very little evidences demonstrate the transfer of improved cognitive abilities during in-clinic training in instrumental activities of daily living such as driving after rehabilitation process (Lew et al., 2009; Lustig, Shah, Seidler, & Reuter-Lorenz, 2009). Specific training requesting simultaneous integration of cognitive functions may improve the transfer of the abilities to the task. Although the majorities of reviewed studies focus on assessment of driving skills and predicting fitness to drive using a driving simulator, driving simulation also offers the opportunity to repeat learning trials and gradually increase task demands by increasing the complexity of manoeuvres. Functionally relevant driving simulator training may increase transfer to on-road driving (Akinwuntan et al., 2012; Schultheis & Rizzo, 2001). This review identified only two articles aiming at rehabilitating driving skills in a TBI population. These two studies demonstrated improvements of driving skills following an in-simulator rehabilitation training. More studies are needed to confirm the potential this method to improve fitness to drive in TBI population.

Driving simulator may be more effective than traditional methods to predict fitness to drive outcome (Akinwuntan et al., 2012; George, Crotty, Gelinas, & Devos, 2014; Lew et al., 2005). In-simulator training should be considered in driving rehabilitation as it may improve ability transfer to the real task which in-clinic rehabilitation have failed to demonstrate (Lew et al., 2009; Lustig et al., 2009). Finally, it is known that TBI drivers develop coping strategies over time (Lundqvist & Alinder, 2007). Driving simulator may provide objectives measures in an ecologically but challenging environment that may enable improvement of driving capacities in TBI individuals.

Conclusion

Driving simulators provides ecologically valid environment; enable the measurement as well as recording of driving parameters and control of stimuli; can be used to evaluate the individual in risky situations in a safe setting; allows the individualisation of training; and, enable the standardization and objectivity of the evaluation process or rehabilitation. Several authors agree on the potential of driving simulators for the assessment and rehabilitation of TBI drivers. Although an insufficient number of studies have investigated the potential of driving assessment and rehabilitation in individuals with TBI using a driving simulator, it seems that this approach is promising. Considerable research efforts are needed to assess the potential and validity of rehabilitation methods using driving simulators in this population.

Declaration of interest

There are no declarations of interest or funding sources to be disclosed by the authors.

Acknowledgements

Sarah Imhoff was supported by a research grant - Recherche en sécurité routière: Fonds de recherche du Québec - Société et culture (FRQSC), Société de l'assurance automobile du Québec (SAAQ), Fonds de recherche du Québec - Santé (FRQS).

Martin Lavallière was supported by a postdoctoral research grant - Recherche en sécurité routière : Fonds de recherche du Québec - Société et culture (FRQSC), Société de l'assurance automobile du Québec (SAAQ), Fonds de recherche du Québec - Santé (FRQS).

Article 3: Training driving ability in traumatic brain injured individual using a driving simulator - A case report

IMHOFF Sarah[1,2], LAVALLIÈRE Martin[3,4], GERMAIN-ROBITAILLE Mathieu[4], *FAIT Philippe[1,2,5]

[1]Département des sciences de l'activité physique, Université du Québec à Trois-Rivières (UQTR), Trois-Rivières, Canada

[2] Groupe de recherche sur les affections neuro-musculo-squelettiques, UQTR, Trois-Rivières, Canada

[3] Massachusetts Institute of Technology AgeLab, Cambridge, USA

[4] Faculté de Médecine, Département de Kinésiologie, Université Laval, Québec, Canada

[5] Centre de recherche en Neuropsychologie et Cognition (CERNEC), Montréal, Canada

Contribution des auteurs

Sarah Imhoff a effectué la collecte et l'analyse des données. Martin Lavallière a créé la plateforme permettant l'évaluation sur simulateur et a collaboré étroitement à l'écriture de l'article. Mathieu Germain-Robitaille a créé le scénario de conduite et a effectué l'extraction des données de performance de conduite. Philippe Fait a élaboré et a créé les documents nécessaires à l'élaboration du projet.

RÉSUMÉ

Introduction. Le traumatisme craniocérébral (TCC) cause des déficits fonctionnels pouvant interférer de manière significative avec de nombreuses activités de la vie quotidienne telles que la conduite automobile. Cette étude rapporte le cas d'une femme de 20 ans ayant perdu son permis de conduire après avoir subi un TCC modéré.

Objective. Nous avons cherché à évaluer l'efficacité d'un programme de réadaptation en simulateur de conduite avec rétroactions automatisées sur les performances de conduite d'un individu ayant subi un TCC.

Méthode. Une femme de 20 ans fut recrutée à l'*Institut de réadaptation en déficience physique de Québec* (IRDPQ) après avoir échoué l'évaluation sur route permettant d'apprécier ses habiletés de conduite. La participante a effectué une évaluation initiale en simulateur ainsi que 11 sessions d'entrainement avec rétroactions spécifiques automatisées en simulateur. Les performances de conduite (temps pour compléter le scénario, contrôle de la vitesse et positionnement latéral du véhicule) furent mesurées en simulateur. Une évaluation finale en simulateur fut conduite.

Résultats. La durée des excès de vitesse a diminué de 1,50 ± 0,80 min (4,16 ± 2,22 %) à 0,45 ± 0,15 min (0,44 ± 0,42 %) lors des entraînements, mais est retournée au niveau initial suite au retrait des rétroactions. Le positionnement latéral du véhicule s'est amélioré avec l'entraînement et s'est maintenu lors du retrait des rétroactions automatisées. La durée des erreurs de conduite attribuées au positionnement latéral a diminué de 18.85 min (53.61 %) lors de l'évaluation initiale à 1.51 min (4.64 %) lors de l'évaluation finale.

Conclusion. Puisque le TCC induit des déficits fonctionnels pouvant affecter la capacité de conduite, il est impératif de développer des méthodes de réadaptation efficaces. Les simulateurs de conduite représentent une avenue thérapeutique intéressante. Des efforts considérables en recherche sont requis pour permettre de confirmer l'efficacité de cette méthode de réadaptation chez les individus ayant subi un TCC.

ABSTRACT

Introduction. Traumatic brain injury (TBI) causes functional deficits that may significantly interfere with numerous activities of daily living such as driving. This study reports the case of a 20-years-old woman having lost her driver's license after sustaining a moderate TBI.

Objective. We aimed to evaluate the effectiveness of an in-simulator training program with automated feedback on driving performance in TBI individual.

Methods. A 20-years-old woman was recruited at the Quebec City Rehabilitation Institute (IRDPQ) after failing the on-road evaluation assessing her fitness to drive in order to reobtain her driving license. The participant underwent an initial in-simulator driving assessment and 11 in-simulator training sessions with driving specific automated feedbacks issued while driving. Driving performance (simulation duration, speed regulation and lateral positioning) was measured in the driving simulator. A final in-simulator driving assessment was performed.

Results. Speeding duration decreased during training sessions from 1.50 ± 0.80 min (4.16 ± 2.22 %) to 0.45 ± 0.15 min (0.44 ± 0.42 %) but returned to initial after removing feedbacks. Lateral positioning improved with training and maintained after feedbacks removal. Time spend in an incorrect lateral position went from 18.85 min (53.61 %) in initial assessment to 1.51 min (4.64 %) on final assessment.

Conclusion. Since TBI induces deficits that may affect driving ability, it is imperative to develop effective rehabilitation methods. Driving simulators represent an

interesting therapeutic avenue. Considerable research efforts are needed to confirm the effectiveness of this method in driving rehabilitation of individuals who sustained a TBI.

Introduction

Traumatic brain injury (TBI) causes functional deficits that may significantly interfere with numerous activities of daily living such as driving (Bottari et al., 2012; Canadian Council of Motor Transport Administrators, 2013; Canadian Institute for Health Information, 2006; Ponsford et al., 2014). Access to driving is a strong symbol of autonomy (Berger et al., 2000; Rapport et al., 2008). Since driving requires operational (basic driving skills as lateral positioning and speed control), tactical (judgment and anticipation) and strategic level of control (route planning) (Bottari et al., 2012; Lundqvist & Alinder, 2007; J. A. Michon, 1989) resuming driving following TBI may be challenging. Thus, only 40-60% of moderate-to-severe TBI individuals return to driving (Bazarian et al., 1999; Bivona et al., 2012; Canadian Council of Motor Transport Administrators, 2013; Coleman et al., 2002; Fisk et al., 1998; Leon-Carrion et al., 2005; Nalder et al., 2012; Novack et al., 2010; Rapport et al., 2008).

Case report

We report the case of a 20-year-old woman who lost her driver's license after sustaining a moderate TBI in May 2013, after a car crash involving a deer. When transferred to intensive care, she presented a score of 10/15 on the Glasgow Coma Scale (GCS) (Teasdale & Jennett, 1974). Following the accident, she presented a post-traumatic amnesia, diffuse axonal injury with several bilateral petechiae, hemorrhagic bifrontales contusions mostly located in the right frontal lobe, an infringement of the third right cranial nerve, mild right optic neuropathy, left hemiparesis, balance impairment (43/56 on Berg Balance Scale (BBS) (Berg, Wood-Dauphinee, Williams, & Maki, 1992)), difficulty in performing activities of daily living (ADLs) and cognitive impairments including: memory impairment, decline in audio-verbal and visual attention, decline in the ability of abstraction, reduced organizational capacity, decreased visuospatial abilities, cognitive fatigability and apathy.

At the time of the accident, the participant held a *Learner's License - Passenger Vehicle (Class 5)* and had very little driving experience. Having failed her first attempt to the *Probationary License - Passenger Vehicle (Class 5)*, she was planning to perform her second attempt to the *Société de l'Assurance Automobile du Québec* (SAAQ) on-road test as required by Quebec's provincial legislation.

In order to regain her *Learner's License - Passenger Vehicle (Class 5)* she had to obtain an evaluation certifying her functional capacity for driving. She underwent an in-clinic assessment which revealed: mild post traumatic cognitive impairments (i.e. cognitive fatigability that interferes with the sustained attention span, vigilance weakness generates a slow reaction time when stimuli appear slowly); sufficient muscle strength, range of motion and coordination; proper reaction time; sufficient overall perceptual-cognitive functions for driving; and, sufficient behavior. Following this assessment, she received a 10-hour on-road driving training with a driving instructor and a 3-hour in-simulator specific road rules learning with a driving instructor. Post trauma subject's driving ability was assessed during an on-road evaluation conducted by an occupational therapist in May 2014 at the Quebec City Rehabilitation Institute (IRDPQ). During this test, the participant did not demonstrate the operational and tactical skills required to drive safely. The difficulties observed during the road test were consistent with cognitive sequelae observed in clinical settings. These seemed to cause functional impairments interfering with her driving performance. Considering the deficiencies observed during the on-road assessment, the lack of improvement during training sessions and integration difficulties of the basics of driving, the improvement potential was estimated as low. Therefore, no other subsequent road test was envisaged by the IRDPQ.

In-simulator driving rehabilitation presents a promising method to improve driving skills after TBI (Cox et al., 2010; Gamache et al., 2011). The aim of this study is to evaluate the effectiveness of an in-simulator training program with automated feedback on driving performance in a TBI individual.

Methods

Procedure

A 20-years-old woman was recruited at the Quebec City Rehabilitation Institute (IRDPQ) after failing the on-road evaluation assessing her fitness to drive in order to reobtain her driving license. The participant underwent 11 in-simulator training sessions (over a 5-week period) with driving specific automated feedbacks on the driving performance issued while driving. An initial and a final in-simulator driving assessment were performed before and after the in-simulator driving rehabilitation training. Feedbacks weren't audible during the simulation-based evaluations. In order to avoid simulators sickness, a 15 min in-simulator straight long-course was conducted before all simulation sessions. Driving training and assessment scenario (27.5 km) integrate 19.6 km of rural and 7.9 km of urban sections. Course includes similar operations to those carried out on the road as lane change, intersection stop signs, traffic lights, turns and overtaking. She was asked to follow Québec's *Highway safety code (R.S.Q, Chapter c-24.2)*.

Automated auditory driving specific feedbacks were issued while driving according to the following criteria: 1) exceeding a speed of 10 km/h above the speed limit and 2) maintaining lateral vehicle position of more than 15 % of the lane width to the left or the right of the center of the lane (ie. tires less than 15 cm from the nearest line) for more than 5 sec. Another warning was sent every ten seconds until the vehicle speed or lateral position decreased under these thresholds. Driving performance represented by simulation duration, speed regulation and lateral positioning was measured in the driving simulator.

Material

Driving simulation was conducted on a fixed-based open-cab simulator which consists of an instrumented sedan (brake and accelerator pedals, steering and automatic transmission). STISIM Drive 3.0 (System Technology Inc., Hawthorne, USA) software displayed image of the driving scene on a 1.2 m high by 1.6 m wide flat screen using a projector Hitachi CPX8 which provides a 40° horizontal by 30° vertical field of view and recorded the driver's performance. Auditory driving stimuli and automated feedbacks were displayed by a digital input/output board (Computer Measurement PCI-DOI24) through apiezo-electric speaker (100ms, 1.5kHz).

Data analysis

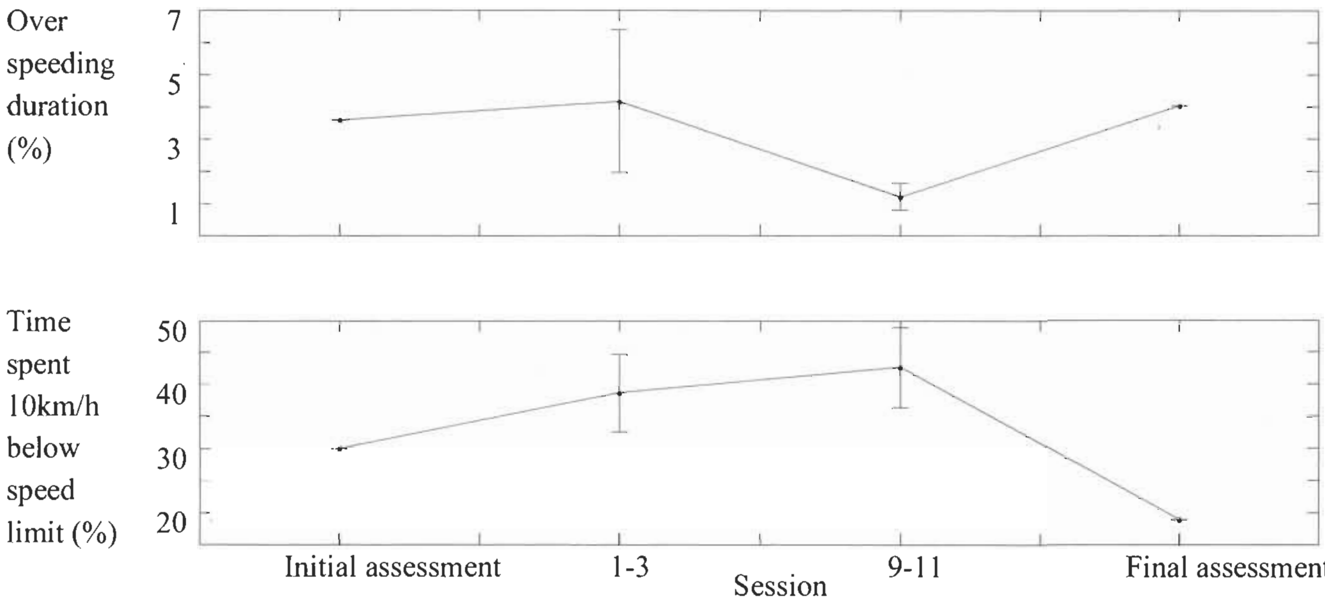
Data analysis was conducted on the initial and final assessment sessions and on training sessions one to three and nine to eleven. Mean and standard deviation are presented in order to simplify training sessions' results. These were selected in order to analyse the effects of training and need for feedbacks on driving performance. Basic simulator data of speed and vehicle lateral position were used to evaluate driving performance (Classen & Brooks, 2014; Hoffman & McDowd, 2010). Exceeding a speed of 10 km/h above and below the speed limit was considered as a speed regulation error. Lateral positioning error was define by maintaining lateral vehicle position of more than 15 % of the lane width to the left or the right of the center of the lane (ie. tires less than 15 cm from the nearest line). Considering the single-case nature of the data collection, descriptive statistics about duration of the simulation, speed regulation and lateral positioning are presented. Speed regulation error and lateral positioning error are represented in function of time recorded by the simulator and was related to total simulation time.

Results

Initial assessment was completed in 35.15 min. On average, the time to complete the scenario was stable in the first three (36.00 ± 0.44 min) and last three (37.33 ± 0.64 min) in-simulator trainings. The participant completed final assessment in 32.63 min.

The participant drove 1.26 min (3.58 %) over the speed limit (> 10 km/h) during initial assessment. This decreased during training sessions from 1.50 ± 0.80 min (4.17 ± 2.23 %) to 0.45 ± 0.15 min (1.20 ± 0.42 %). Upon removal of feedbacks for the final assessment, speeding went back to the initial duration (1.31 min, 4.00 %). Even if, no feedbacks regarding speed below speed limit was issued during training, we measured the time during which the participant was driving lessthan 10 km/h below speed limit. After removing mandatory stops and red light intersections, time spent driving too slowly initially at 10.56 min (30.04 %) increased when initiating feedback at 13.92 ± 2.39 min (38.63 ± 6.15 %) for the tree first training sessions and 15.95 ± 2.59 min (42.65 ± 6.26 %) on sessions nine to eleven. Time spent driving too slowly decreased greatly during the final evaluation (6.18 min, 18.94 %). Speed regulation results are presented in Figure 4.

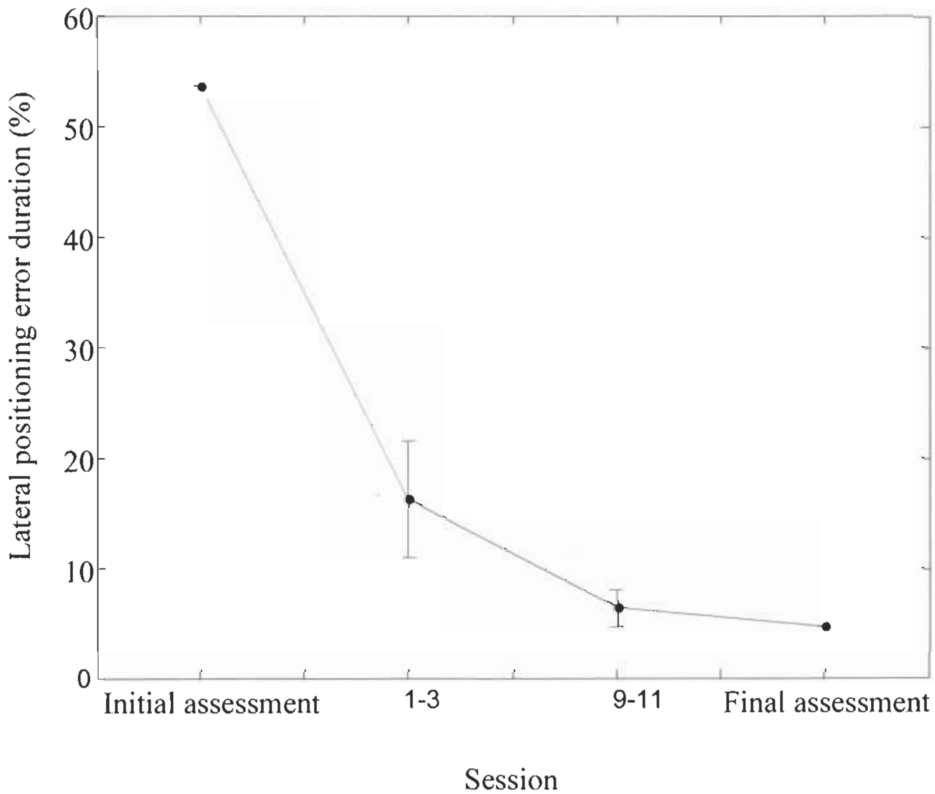
Figure 4: Speed regulation results



Proportion of over speeding duration relative to the simulation duration (%) in function of session (top panel).
Proportion of slow driving relative to the simulation duration (%) in function of session (lower panel).

The maintenance of the vehicle lateral position in more than one standard deviation to the left or the right of the center of the lane was considered as a driving error. She spent 18.85 min (53.61 %) in an incorrect lateral position situation in initial assessment. On the initiation of feedbacks, time spent in an improper lane positioning decreased and was maintained over time for training sessions one to three (5.83 ± 1.84 min, 16.23 ± 5.25 %), nine to eleven (2.37 ± 0.66 min, 6.34 ± 1.70 %) and on final assessment without feedback (1.51 min, 4.64 %). These results are presented in Figure 5.

Figure 5: Proportion of incorrect lateral positioning's duration



Proportion of incorrect lateral positioning's duration relative to the simulation duration (%) in function of session.

Discussion

The objective was to report the driving adaptations following of an in-simulator driving rehabilitation training program with automated feedback on driving performance in TBI individual. Improvement in speed regulation and lateral positioning were observed through the in-simulator training sessions.

The participant responded to specific auditory feedbacks at training by reducing speeding error duration. However, this adaptation was not maintained after removing feedback. In general, the participant was driving too slowly during training. On the other side, time to complete the scenario was shorter on final assessment which represents a higher overall speed without impacts on speeding duration. This may indicate that participant was more attentive to speed regulation after the in-simulator training program. We have to consider that the participant aimed to regain her driving license. Therefore, she had to obtain an evaluation certifying her functional capacity for driving. Before the in-simulator final assessment, the participant had access to an on-road learning session thru the IRDPQ driving rehabilitation program during which the driving instructor told her that she was driving too slowly. This may impacted her driving behavior and may explain higher overall speed on final assessment. Lateral positioning improved greatly with training and maintained after feedback removal. This indicated that the introduction of real-time feedback emission impacted this specific driving behavior.

To our knowledge, only two other studies aimed to rehabilitate fitness to drive in TBI drivers using in-simulator training program. Our results are consistent with those of Cox et al. (2010) and Gamache et al. (2011) which demonstrated improvements of driving skills such as lateral positioning, speed regulation, steering through turns and brake control following an in-simulator rehabilitation training. Thru this article, we demonstrated that automated auditory driving specific feedbacks may be beneficial when issued while driving during an in-simulator training. In-simulator driving performance seems to be improved by training. Participant's dependence to feedbacks and transfer of driving improvements to on-road driving task remain unclear. At the end of this study, her functional capacity for driving was assessed by an on-road driving evaluation conducted by an occupational therapist (Michon, 1985). The occupational therapist concluded that, in comparison with the previous on-road test conducted in May, the participant presented improved operational skills. Although some tactical skills improvements were observed, anticipation, situation analysis, planning, attention and vigilance were not compatible with safety aspect of driving. The participant demonstrated appropriate operational skills but not tactical skills that allow her to drive in compliance with road safety. Therefore, her *Learner's License - Passenger Vehicle (Class 5)* was not renewed. Several studies demonstrated that novice drivers show a wide range of driving deficits when compared to experience drivers (Borowsky & Oron-Gilad, 2013; Chan et al., 2010; Chapman & Underwood, 1998; Durbin et al., 2014; Fisher et al., 2002; Laapotti, Keskinen, Hatakka, & Katila, 2001; Lehtonen, Lappi, Koirikivi, & Summala, 2014; McKnight & McKnight, 2003; Parmet, Borowsky, Yona, & Oron-Gilad, 2015; Ross et al., 2014; Scialfa et al., 2012; Scott, Hall, Litchfield, & Westwood, 2013; Underwood, 2013). Moreover, novice drivers may successfully develop basics operational driving skills thru training without develop tactical skills required to safety driving (Durbin et al., 2014; Groeger & Banks, 2007; Laapotti et al., 2001). Therefore, although deficits observed during the on-road assessment have been attributed to post-traumatic sequelae, contribution of participant's driving experience in driving dysfunction should be considered. Further, our in-simulator specific feedbacks focused on operational skills thru an unique training scenario with limited range of challenging situations on a short period and could be insufficient to improve tactical skills.

Conclusion

This pilot study shows that a TBI individual responded positively to feedback during an in-simulator driving rehabilitation training program. The participant's dependence to feedbacks and transfer of driving improvements to on-road driving task remain unclear. Following the intervention, her *Learner's License - Passenger Vehicle (Class 5)* was not renewed. Since TBI causes functional deficits that may affect ability to drive, it is imperative to develop effective rehabilitation method. In-simulator driving rehabilitation training may represent an interesting therapeutic avenue. Although an insufficient number of studies have investigated the potential of driving rehabilitation, considerable research efforts are needed to confirm the effectiveness of this method in driving rehabilitation of TBI individuals.

DISCUSSION GÉNÉRALE

Suite à un TCC, la plasticité du cerveau pourrait répondre à différents types d'entraînements spécifiques ayant un impact positif sur les déficits induits par le trauma tel que présenté dans le contexte de ce mémoire de maîtrise. Ainsi, la stimulation spécifique de certaines voies neuronales pourrait promouvoir la réadaptation postcommotionnelle en particulier des fonctions cognitive et motrices en favorisant la neuroplasticité (Bach-y-Rita, 2003; Kozlowski, Leasure, & Schallert, 2013; Tomaszczyk et al., 2014; Villamar, Santos Portilla, Fregni, & Zafonte, 2012). Des évidences montrent que l'entraînement incluant l'apprentissage de nouvelles compétences induit un changement spécifique dans les zones motrices du cortex cérébral (Villamar et al., 2012). Ceci explique le rationnel derrière l'intégration d'exercices de coordination et d'équilibre au programme de réadaptation présentés dans le chapitre 2 et l'entraînement de la capacité de conduire sur simulateur présenté dans le chapitre 3. Finalement, des études menées chez l'animal ont démontré que l'entrainement aérobie pourrait promouvoir la neuroplasticité (Archer et al., 2012; Griesbach, 2011; Griesbach, Gomez-Pinilla, et al., 2004; Griesbach, Hovda, & Gomez-Pinilla, 2009; Griesbach, Hovda, et al., 2004). Ce mémoire met aussi en évidence l'amélioration des signes et symptômes en réponse à un entraînement de type aérobie chez des enfants et adolescents qui récupèrent de manière atypique suite à un TCCL. Il a récemment été postulé qu'une atteinte de la fonction vasculaire cérébrale (plus particulièrement de l'autorégulation cérébrale et de la réactivité vasculaire au dioxyde de carbone) pourrait contribuer en partie à la présence des symptômes postcommotionnels tels l'altération des fonctions cognitives, les céphalées, les vertiges, etc. (Amonette & Mossberg, 2013; Bailey et al., 2013; Clausen, Pendergast, Willer, & Leddy, 2015; Conder & Conder, 2014; Gardner et al., 2014; Kenney et al., 2015; Len & Neary, 2011; Len et al., 2013; Meier et al., 2015; Sours, Zhuo, Roys, Shanmuganathan, & Gullapalli, 2015; Svaldi et al., 2015; Tan, Meehan, Iverson, & Taylor, 2014b). Dans ce sens, la présence d'une dysfonction vasculaire cérébrale pourrait contribuer à la chronicité ou persistance des symptômes post-traumatiques et à l'intolérance à l'effort suite à un TCCL (Clausen et al., 2015). Cependant, le rôle de la fonction vasculaire cérébrale, caractérisée de manière intégrée par l'autorégulation cérébrale, la réactivité des vaisseaux cérébraux au CO_2 et le couplage neurovasculaire, chez les sujets qui récupèrent de manière atypique suivant un TCCL n'a été exploré que brièvement à notre connaissance. L'entrainement de type aérobie pourrait permettre de réduire la dysfonction vasculaire cérébrale des sujets ayant subi un TCCL par l'amélioration de l'autorégulation cérébrale (Amonette & Mossberg, 2013; Baker et al., 2012; Conder & Conder, 2014). Ceci pourrait expliquer l'amélioration des symptômes suite à un entrainement comportant une activité de type cardiovasculaire tel que décrit dans le chapitre 2. Les résultats de ce programme de réadaptation sont semblables à ceux observés chez l'adulte (Leddy et al., 2013; Leddy et al., 2010) et chez les jeunes (Gagnon et al., 2009; Gagnon et al., 2015) lors de programmes de réadaptation similaires.

CONCLUSION GÉNÉRALE

Le traumatisme craniocérébral représente un défi pour la communauté médicale considérant la constellation des déficits et des symptômes que crée cette atteinte. La réadaptation des individus ne récupérant pas complètement des suites d'un TCC est mal documentée. Plusieurs études sont requises pour comprendre les phénomènes qui limitent la récupération suivant le TCC. De plus, l'élaboration de guide de traitement pour la population qui ne récupère pas complètement à la suite d'un TCC est requise. Il est urgent de concevoir et d'évaluer les interventions qui sont basées sur des données probantes cliniquement réalisables et écologiquement valables chez la population pédiatrique. De même, il est impératif de trouver des méthodes d'évaluation et de réadaptation sécuritaires des habiletés de conduite dans la population ayant subi un TCC. Il semble que l'entraînement spécifique est une avenue thérapeutique intéressante permettent la récupération chez les individus ayant subi un TCC. Le projet de maîtrise présenté démontre que l'entraînement physique progressif pourrait représenter un atout important lors de la réadaptation des jeunes qui récupèrent de manière atypique suivant un TCCL et aurait un effet positif sur l'importance des symptômes post-commotionnels auto-rapportés. Dans le même ordre d'idée, l'entraînement spécifique des habiletés de conduite sur simulateur représente une avenue prometteuse lors de la réadaptation des capacités de conduite chez les personnes ayant subi un TCC. Dans ce sens, l'entraînement, le point commun des études réalisées dans le cadre de ce projet de maîtrise, est un élément clé de la réadaptation des sujets ayant subi un TCC. Puisque ces projets sont inspirés des activités cliniques, ceux-ci ont le potentiel d'influencer la pratique et la recherche en traumatologie.

RÉFÉRENCES

Akinwuntan, A. E., De Weerdt, W., Feys, H., Pauwels, J., Baten, G., Arno, P., & Kiekens, C. (2005). Effect of simulator training on driving after stroke: a randomized controlled trial. *Neurology, 65*(6), 843-850.

Akinwuntan, A. E., Wachtel, J., & Rosen, P. N. (2012). Driving simulation for evaluation and rehabilitation of driving after stroke. *J Stroke Cerebrovasc Dis, 21*(6), 478-486.

Amick, M. M., Kraft, M., & McGlinchey, R. (2013). Driving simulator performance of veterans from the Iraq and Afghanistan wars. *J Rehabil Res Dev, 50*(4), 463-470.

Amonette, W. E., & Mossberg, K. A. (2013). Ventilatory anaerobic thresholds of individuals recovering from traumatic brain injury compared with noninjured controls. *J Head Trauma Rehabil, 28*(5).

Archer, T. (2012). Influence of physical exercise on traumatic brain injury deficits: scaffolding effect. *Neurotox Res, 21*(4), 418-434.

Archer, T., Svensson, K., & Alricsson, M. (2012). Physical exercise ameliorates deficits induced by traumatic brain injury. *Acta Neurol Scand, 125*(5), 293-302.

Bach-y-Rita, P. (2003). Theoretical basis for brain plasticity after a TBI. *Brain Inj, 17*(8), 643-651. doi: 10.1080/0269905031000107133

Bailey, D. M., Jones, D. W., Sinnott, A., Brugniaux, J. V., New, K. J., Hodson, D., . . . Ainslie, P. N. (2013). Impaired cerebral haemodynamic function associated with chronic traumatic brain injury in professional boxers. *Clin Sci, 124*(3), 177-189.

Baker, J. G., Freitas, M. S., Leddy, J. J., Kozlowski, K. F., & Willer, B. S. (2012). Return to full functioning after graded exercise assessment and progressive exercise treatment of postconcussion syndrome. *Rehabil Res Pract, 705309*(10), 16.

Barlow, K. M., Crawford, S., Stevenson, A., Sandhu, S. S., Belanger, F., & Dewey, D. (2010). Epidemiology of postconcussion syndrome in pediatric mild traumatic brain injury. *Pediatrics, 126*(2), 2009-0925.

Bazarian, J. J., Wong, T., Harris, M., Leahey, N., Mookerjee, S., & Dombovy, M. (1999). Epidemiology and predictors of post-concussive syndrome after minor head injury in an emergency population. *Brain Inj, 13*(3), 173-189.

Bedard, M. B., Parkkari, M., Weaver, B., Riendeau, J., & Dahlquist, M. (2010). Assessment of driving performance using a simulator protocol: validity and reproducibility. *Am J Occup Ther, 64*(2), 336-340.

Berg, K. O., Wood-Dauphinee, S. L., Williams, J. I., & Maki, B. (1992). Measuring balance in the elderly: validation of an instrument. *Can J Public Health, 83 Suppl 2*, S7-11.

Berger, J. T., Rosner, F., Kark, P., & Bennett, A. J. (2000). Reporting by physicians of impaired drivers and potentially impaired drivers. The Committee on Bioethical Issues of the Medical Society of the State of New York. *J Gen Intern Med, 15*(9), 667-672.

Bigler, E. D. (2008). Neuropsychology and clinical neuroscience of persistent post-concussive syndrome. *J Int Neuropsychol Soc, 14*(1), 1-22.

Bivona, U., D'Ippolito, M., Giustini, M., Vignally, P., Longo, E., Taggi, F., & Formisano, R. (2012). Return to driving after severe traumatic brain injury: increased risk of traffic accidents and personal responsibility. *J Head Trauma Rehabil, 27*(3), 210-215.

Bleiberg, J., Cernich, A. N., Cameron, K., Sun, W., Peck, K., Ecklund, P. J., . . . Warden, D. L. (2004). Duration of cognitive impairment after sports concussion. *Neurosurgery, 54*(5), 1073-1078; discussion 1078-1080.

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Med Sci Sports Exerc, 14*(5), 377-381.

Borowsky, A., & Oron-Gilad, T. (2013). Exploring the effects of driving experience on hazard awareness and risk perception via real-time hazard identification, hazard classification, and rating tasks. *Accid Anal Prev, 59*, 548-565. doi: 10.1016/j.aap.2013.07.008

Bottari, C., Lamothe, M. P., Gosselin, N., Gelinas, I., & Ptito, A. (2012). Driving difficulties and adaptive strategies: the perception of individuals having sustained a mild traumatic brain injury. *Rehabil Res Pract, 837301*(10), 13.

Brand, S., Gerber, M., Beck, J., Hatzinger, M., Puhse, U., & Holsboer-Trachsler, E. (2010). High exercise levels are related to favorable sleep patterns and psychological functioning in adolescents: a comparison of athletes and controls. *J Adolesc Health, 46*(2), 133-141.

Brouwer, W. H., Withaar, F. K., Tant, M. L., & van Zomeren, A. H. (2002). Attention and driving in traumatic brain injury: a question of coping with time-pressure. *J Head Trauma Rehabil, 17*(1), 1-15.

Brown, A. W., Elovic, E. P., Kothari, S., Flanagan, S. R., & Kwasnica, C. (2008). Congenital and acquired brain injury. 1. Epidemiology, pathophysiology, prognostication, innovative treatments, and prevention. *Arch Phys Med Rehabil, 89*(3 Suppl 1), 001.

Bruininks, R., & Bruininks, B. (2005). Bruininks-Oseretsky test of motor proficiency (2nd ed.). *Minneapolis, MN: NCS Pearson.*

Canadian Council of Motor Transport Administrators. (2013). Determining Driver Fitness in Canada: Part 1: Administration of Driver Fitness Programs and Part 2: CCMTA Medical Standards for Drivers *CCMTA Reports*(Edition 13), 1-317.

Canadian Institute for Health Information. (2006). Head injuries in Canada: A Decade of Change (1994-1995 to 2003-2004). Retrieved from www.cihi.ca

Canadian Institute for Health Information. (2007). *The burden of Neurological Diseases, Disorders and Injuries in Canada.*

Canadian Medical Association. (2012). *CMA Driver's Guide : Determining medical fitness to operate motor vehicles 8th ed.*: Retrieved from www.cma.ca/driversguide.

Cantin, V., Lavalliere, M., Simoneau, M., & Teasdale, N. (2009). Mental workload when driving in a simulator: effects of age and driving complexity. *Accid Anal Prev, 41*(4), 763-771.

Cassidy, J. D., Carroll, L. J., Peloso, P. M., Borg, J., von Holst, H., Holm, L., . . . Coronado, V. G. (2004). Incidence, risk factors and prevention of mild traumatic brain injury: results of the WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury. *J Rehabil Med, 43*, 28-60.

Chan, E., Pradhan, A. K., Pollatsek, A., Knodler, M. A., & Fisher, D. L. (2010). Are Driving Simulators Effective Tools for Evaluating Novice Drivers' Hazard Anticipation, Speed Management, and Attention Maintenance Skills. *Transp Res Part F Traffic Psychol Behav, 13*(5), 343-353. doi: 10.1016/j.trf.2010.04.001

Chapman, P. R., & Underwood, G. (1998). Visual search of driving situations: danger and experience. *Perception, 27*(8), 951-964.

Chaumet, G., Quera-Salva, M. A., Macleod, A., Hartley, S., Taillard, J., Sagaspe, P., . . . Philip, P. (2008). Is there a link between alertness and fatigue in patients with traumatic brain injury? *Neurology, 71*(20), 1609-1613.

Chin, L. M., Chan, L., Woolstenhulme, J. G., Christensen, E. J., Shenouda, C. N., & Keyser, R. E. (2014). Improved Cardiorespiratory Fitness With Aerobic Exercise Training in Individuals With Traumatic Brain Injury. *J Head Trauma Rehabil, 4*, 4.

Classen, S., & Brooks, J. (2014). Driving simulators for occupational therapy screening, assessment, and intervention. *Occupational Therapy in Health Care, 28*(2), 154-162.

Classen, S., Levy, C., McCarthy, D., Mann, W. C., Lanford, D., & Waid-Ebbs, J. K. (2009). Traumatic brain injury and driving assessment: an evidence-based literature review. *Am J Occup Ther, 63*(5), 580-591.

Classen, S., Levy, C., Meyer, D. L., Bewernitz, M., Lanford, D. N., & Mann, W. C. (2011). Simulated driving performance of combat veterans with mild tramatic brain injury and posttraumatic stress disorder: a pilot study. *Am J Occup Ther, 65*(4), 419-427.

Clausen, M., Pendergast, D. R., Willer, B., & Leddy, J. (2015). Cerebral Blood Flow During Treadmill Exercise Is a Marker of Physiological Postconcussion Syndrome in Female Athletes. *J Head Trauma Rehabil, 19*, 19.

Cohen, H., Blatchly, C. A., & Gombash, L. L. (1993). A study of the clinical test of sensory interaction and balance. *Phys Ther, 73*(6), 346-351; discussion 351-344.

Coleman, R. D., Rapport, L. J., Ergh, T. C., Hanks, R. A., Ricker, J. H., & Millis, S. R. (2002). Predictors of driving outcome after traumatic brain injury. *Arch Phys Med Rehabil, 83*(10), 1415-1422.

Conder, R. L., & Conder, A. A. (2014). Heart rate variability interventions for concussion and rehabilitation. *Front Psychol, 5*(890).

Conners, C. K., & Staff, M. H. S. . (2000). Conners' Continuous Performance Test II (CPT II V. 5). *North Tonawanda, NY: Multi-Health Systems Inc, 1-16.*

Cooper, D. B., Bunner, A. E., Kennedy, J. E., Balldin, V., Tate, D. F., Eapen, B. C., & Jaramillo, C. A. (2015). Treatment of persistent post-concussive symptoms after mild traumatic brain injury: a systematic review of cognitive rehabilitation and behavioral health interventions in military service members and veterans. *Brain Imaging Behav, 9*(3), 403-420. doi: 10.1007/s11682-015-9440-2

Corrigan, J. D. (2001). Conducting statewide needs assessments for persons with traumatic brain injury. *J Head Trauma Rehabil, 16*(1), 1-19.

Corrigan, J. D., Selassie, A. W., & Orman, J. A. (2010). The epidemiology of traumatic brain injury. *J Head Trauma Rehabil, 25*(2), 72-80.

Cox, D. J., Davis, M., Singh, H., Barbour, B., Nidiffer, F. D., Trudel, T., . . . Moncrief, R. (2010). Driving rehabilitation for military personnel recovering from traumatic brain injury using virtual reality driving simulation: a feasibility study. *Mil Med, 175*(6), 411-416.

Cyr, A. A., Stinchcombe, A., Gagnon, S., Marshall, S., Hing, M. M., & Finestone, H. (2009). Driving difficulties of brain-injured drivers in reaction to high-crash-risk simulated road events: a question of impaired divided attention? *J Clin Exp Neuropsychol, 31*(4), 472-482.

de Winter, J. C., de Groot, S., Mulder, M., Wieringa, P. A., Dankelman, J., & Mulder, J. A. (2009). Relationships between driving simulator performance and driving test results. *Ergonomics, 52*(2), 137-153.

Delis, D. C., Kaplan, E., & Kramer, J. H. . (2001). Delis-Kaplan executive function system (D-KEFS). *Psychological Corporation.*

DeMatteo, C., Volterman, K. A., Breithaupt, P. G., Claridge, E. A., Adamich, J., & Timmons, B. W. (2015). Exertion Testing in Youth with Mild Traumatic Brain Injury/Concussion. *Med Sci Sports Exerc, 11*, 11.

Department of Veterans Affairs/Department of Defense. (2009). VA/DoD Clinical Practice Guideline for Management of Concussion/Mild Traumatic Brain Injury. *J Rehabil Res Dev, 46*(6), CP1-68.

Di Stefano, M., & Macdonald, W. (2003). Assessment of older drivers: relationships among on-road errors, medical conditions and test outcome. *J Safety Res, 34*(4), 415-429.

Durbin, D. R., Mirman, J. H., Curry, A. E., Wang, W., Fisher Thiel, M. C., Schultheis, M., & Winston, F. K. (2014). Driving errors of learner teens: frequency, nature and their association with practice. *Accid Anal Prev, 72*, 433-439. doi: 10.1016/j.aap.2014.07.033

Ensari, I., Greenlee, T. A., Motl, R. W., & Petruzzello, S. J. (2015). META-ANALYSIS OF ACUTE EXERCISE EFFECTS ON STATE ANXIETY: AN UPDATE OF RANDOMIZED CONTROLLED TRIALS OVER THE PAST 25 YEARS. *Depress Anxiety*. doi: 10.1002/da.22370

Fait, P., McFadyen, B. J., Swaine, B., & Cantin, J. F. (2009). Alterations to locomotor navigation in a complex environment at 7 and 30 days following a concussion in an elite athlete. *Brain Inj, 23*(4), 362-369. doi: 10.1080/02699050902788485

Fisher, D. L., Laurie, N. E., Glaser, R., Connerney, K., Pollatsek, A., Duffy, S. A., & Brock, J. (2002). Use of a fixed-base driving simulator to evaluate the effects of experience and PC-based risk awareness training on drivers' decisions. *Hum Factors, 44*(2), 287-302.

Fisk, G. D., Schneider, J. J., & Novack, T. A. (1998). Driving following traumatic brain injury: prevalence, exposure, advice and evaluations. *Brain Inj, 12*(8), 683-695.

Formisano, R., Bivona, U., Brunelli, S., Giustini, M., Longo, E., & Taggi, F. (2005). A preliminary investigation of road traffic accident rate after severe brain injury. *Brain Inj, 19*(3), 159-163.

Gagnon, I., Galli, C., Friedman, D., Grilli, L., & Iverson, G. L. (2009). Active rehabilitation for children who are slow to recover following sport-related concussion. *Brain Inj, 23*(12), 956-964.

Gagnon, I., Grilli, L., Friedman, D., & Iverson, G. L. (2015). A pilot study of active rehabilitation for adolescents who are slow to recover from sport-related concussion. *Scand J Med Sci Sports*. doi: 10.1111/sms.12441

Galski, T., Bruno, R. L., & Ehle, H. T. (1992). Driving after cerebral damage: a model with implications for evaluation. *Am J Occup Ther, 46*(4), 324-332.

Gamache, P. L., Lavalliere, M., Tremblay, M., Simoneau, M., & Teasdale, N. (2011). In-simulator training of driving abilities in a person with a traumatic brain injury. *Brain Inj, 25*(4), 416-425.

Gardner, A. J., Tan, C. O., Ainslie, P. N., van Donkelaar, P., Stanwell, P., Levi, C. R., & Iverson, G. L. (2014). Cerebrovascular reactivity assessed by transcranial Doppler ultrasound in sport-related concussion: a systematic review. *Br J Sports Med*. doi: 10.1136/bjsports-2014-093901

George, S., Crotty, M., Gelinas, I., & Devos, H. (2014). Rehabilitation for improving automobile driving after stroke. *Cochrane Database Syst Rev, 25*(2).

Giza, C. C., & Hovda, D. A. (2001). The Neurometabolic Cascade of Concussion. *J Athl Train, 36*(3), 228-235.

Giza, C. C., Kutcher, J. S., Ashwal, S., Barth, J., Getchius, T. S., Gioia, G. A., . . . Zafonte, R. (2013). Summary of evidence-based guideline update: evaluation and management of concussion in sports: report of the Guideline Development Subcommittee of the American Academy of Neurology. *Neurology, 80*(24), 2250-2257. doi: 10.1212/WNL.0b013e31828d57dd

Griesbach, G. S. (2011). Exercise after traumatic brain injury: is it a double-edged sword? *Pm R, 3*(6 Suppl 1), 008.

Griesbach, G. S., Gomez-Pinilla, F., & Hovda, D. A. (2004). The upregulation of plasticity-related proteins following TBI is disrupted with acute voluntary exercise. *Brain Res, 6*(2), 154-162.

Griesbach, G. S., Hovda, D. A., & Gomez-Pinilla, F. (2009). Exercise-induced improvement in cognitive performance after traumatic brain injury in rats is dependent on BDNF activation. *Brain Res, 8*, 105-115.

Griesbach, G. S., Hovda, D. A., Molteni, R., Wu, A., & Gomez-Pinilla, F. (2004). Voluntary exercise following traumatic brain injury: brain-derived neurotrophic factor upregulation and recovery of function. *Neuroscience, 125*(1), 129-139.

Groeger, J. A., & Banks, A. P. (2007). Anticipating the content and circumstances of skill transfer: unrealistic expectations of driver training and graduated licensing? *Ergonomics, 50*(8), 1250-1263. doi: 10.1080/00140130701318723

Guerrero, J. L., Thurman, D. J., & Sniezek, J. E. (2000). Emergency department visits associated with traumatic brain injury: United States, 1995-1996. *Brain Inj, 14*(2), 181-186.

Guskiewicz, K. M. (2003). Assessment of postural stability following sport-related concussion. *Curr Sports Med Rep, 2*(1), 24-30.

Guskiewicz, K. M., & Register-Mihalik, J. K. (2011). Postconcussive impairment differences across a multifaceted concussion assessment protocol. *PM R, 3*(10 Suppl 2), S445-451. doi: 10.1016/j.pmrj.2011.08.009

Guskiewicz, K. M., Ross, S. E., & Marshall, S. W. (2001). Postural Stability and Neuropsychological Deficits After Concussion in Collegiate Athletes. *J Athl Train, 36*(3), 263-273.

Halstead, M. E., & Walter, K. D. (2010). American Academy of Pediatrics. Clinical report--sport-related concussion in children and adolescents. *Pediatrics, 126*(3), 597-615. doi: 10.1542/peds.2010-2005

Hartvigsen, J., Boyle, E., Cassidy, J. D., & Carroll, L. J. (2014). Mild traumatic brain injury after motor vehicle collisions: what are the symptoms and who treats them? A population-based 1-year inception cohort study. *Arch Phys Med Rehabil, 95*(3 Suppl), 029.

Hawley, C. A. (2001). Return to driving after head injury. *J Neurol Neurosurg Psychiatry, 70*(6), 761-766.

Hoffman, L., & McDowd, J. M. (2010). Simulator driving performance predicts accident reports five years later. *Psychol Aging, 25*(3), 741-745.

Hotting, K., & Roder, B. (2013). Beneficial effects of physical exercise on neuroplasticity and cognition. *Neurosci Biobehav Rev, 25*(13), 00101-00102.

Huchler S, J. A., Golz D, Küst J, Netz J, Hömberg V, Karbe H. (2002). Evaluation of driving simulation. *Europa Medicophysica, 37*(4), 283-289.

Kelly, D. F., & Becker, D. P. (2001). Advances in management of neurosurgical trauma: USA and Canada. *World J Surg, 25*(9), 1179-1185.

Kenney, K., Amyot, F., Haber, M., Pronger, A., Bogoslovsky, T., Moore, C., & Diaz-Arrastia, R. (2015). Cerebral Vascular Injury in Traumatic Brain Injury. *Exp Neurol*. doi: 10.1016/j.expneurol.2015.05.019

King, L. A., Horak, F. B., Mancini, M., Pierce, D., Priest, K. C., Chesnutt, J., . . . Chapman, J. C. (2014). Instrumenting the balance error scoring system for use with patients reporting persistent balance problems after mild traumatic brain injury. *Arch Phys Med Rehabil, 95*(2), 353-359. doi: 10.1016/j.apmr.2013.10.015

Korner-Bitensky, N., Bitensky, J., Sofer, S., Man-Son-Hing, M., & Gelinas, I. (2006). Driving evaluation practices of clinicians working in the United States and Canada. *Am J Occup Ther, 60*(4), 428-434.

Kotterba, S., Orth, M., Eren, E., Fangerau, T., & Sindern, E. (2003). Assessment of driving performance in patients with relapsing-remitting multiple sclerosis by a driving simulator. *Eur Neurol, 50*(3), 160-164.

Kozlowski, D. A., Leasure, J. L., & Schallert, T. (2013). The control of movement following traumatic brain injury. *Compr Physiol, 3*(1), 121-139.

Kraft, M., Amick, M. M., Barth, J. T., French, L. M., & Lew, H. L. (2010). A review of driving simulator parameters relevant to the Operation Enduring Freedom/Operation Iraqi Freedom veteran population. *Am J Phys Med Rehabil, 89*(4), 336-344.

Krasny-Pacini, A., Chevignard, M., & Evans, J. (2014). Goal Management Training for rehabilitation of executive functions: a systematic review of effectiveness in patients with acquired brain injury. *Disabil Rehabil, 36*(2), 105-116. doi: 10.3109/09638288.2013.777807

Laapotti, S., Keskinen, E., Hatakka, M., & Katila, A. (2001). Novice drivers' accidents and violations--a failure on higher or lower hierarchical levels of driving behaviour. *Accid Anal Prev, 33*(6), 759-769.

Lane, A. K., & Benoit, D. (2011). Driving, brain injury and assistive technology. *NeuroRehabilitation, 28*(3), 221-229.

Larun, L., Brurberg, K. G., Odgaard-Jensen, J., & Price, J. R. (2015). Exercise therapy for chronic fatigue syndrome. *Cochrane Database Syst Rev, 2*, CD003200. doi: 10.1002/14651858.CD003200.pub3

Lavalliere, M., Laurendeau, D., Simoneau, M., & Teasdale, N. (2011). Changing lanes in a simulator: effects of aging on the control of the vehicle and visual inspection of mirrors and blind spot. *Traffic Inj Prev, 12*(2), 191-200.

Leddy, J. J., Baker, J. G., Kozlowski, K., Bisson, L., & Willer, B. (2011). Reliability of a graded exercise test for assessing recovery from concussion. *Clin J Sport Med, 21*(2), 89-94.

Leddy, J. J., Cox, J. L., Baker, J. G., Wack, D. S., Pendergast, D. R., Zivadinov, R., & Willer, B. (2013). Exercise treatment for postconcussion syndrome: a pilot study of changes in functional magnetic resonance imaging activation, physiology, and symptoms. *J Head Trauma Rehabil, 28*(4), 241-249.

Leddy, J. J., Kozlowski, K., Donnelly, J. P., Pendergast, D. R., Epstein, L. H., & Willer, B. (2010). A preliminary study of subsymptom threshold exercise training for refractory post-concussion syndrome. *Clin J Sport Med, 20*(1), 21-27.

Lee, H. C., Cameron, D., & Lee, A. H. (2003). Assessing the driving performance of older adult drivers: on-road versus simulated driving. *Accid Anal Prev, 35*(5), 797-803.

Lehtonen, E., Lappi, O., Koirikivi, I., & Summala, H. (2014). Effect of driving experience on anticipatory look-ahead fixations in real curve driving. *Accid Anal Prev, 70*, 195-208. doi: 10.1016/j.aap.2014.04.002

Len, T. K., & Neary, J. P. (2011). Cerebrovascular pathophysiology following mild traumatic brain injury. *Clin Physiol Funct Imaging, 31*(2), 85-93.

Len, T. K., Neary, J. P., Asmundson, G. J., Candow, D. G., Goodman, D. G., Bjornson, B., & Bhambhani, Y. N. (2013). Serial monitoring of CO2 reactivity following sport concussion using hypocapnia and hypercapnia. *Brain Inj, 27*(3), 346-353. doi: 10.3109/02699052.2012.743185

Lengenfelder, J., Schultheis, M. T., Al-Shihabi, T., Mourant, R., & DeLuca, J. (2002). Divided attention and driving: a pilot study using virtual reality technology. *J Head Trauma Rehabil, 17*(1), 26-37.

Leon-Carrion, J., Dominguez-Morales, M. R., & Martin, J. M. (2005). Driving with cognitive deficits: neurorehabilitation and legal measures are needed for driving again after severe traumatic brain injury. *Brain Inj, 19*(3), 213-219.

Lew, H. L., Poole, J. H., Lee, E. H., Jaffe, D. L., Huang, H. C., & Brodd, E. (2005). Predictive validity of driving-simulator assessments following traumatic brain injury: a preliminary study. *Brain Inj, 19*(3), 177-188.

Lew, H. L., Rosen, P. N., Thomander, D., & Poole, J. H. (2009). The potential utility of driving simulators in the cognitive rehabilitation of combat-returnees with traumatic brain injury. *J Head Trauma Rehabil, 24*(1), 51-56.

Lundin, A., de Boussard, C., Edman, G., & Borg, J. (2006). Symptoms and disability until 3 months after mild TBI. *Brain Inj, 20*(8), 799-806. doi: 10.1080/02699050600744327

Lundqvist, A., & Alinder, J. (2007). Driving after brain injury: self-awareness and coping at the tactical level of control. *Brain Inj, 21*(11), 1109-1117.

Lundqvist, A., Alinder, J., Modig-Arding, I., & Samuelsson, K. (2011). Driving after Brain Injury: A Clinical Model Based on a Quality Improvement Project. *SciRes, 2*(6), 615-623. doi: 10.4236/psych.2011.26094

Lustig, C., Shah, P., Seidler, R., & Reuter-Lorenz, P. A. (2009). Aging, training, and the brain: a review and future directions. *Neuropsychol Rev, 19*(4), 504-522. doi: 10.1007/s11065-009-9119-9

Majerske, C. W., Mihalik, J. P., Ren, D., Collins, M. W., Reddy, C. C., Lovell, M. R., & Wagner, A. K. (2008). Concussion in sports: postconcussive activity levels, symptoms, and neurocognitive performance. *J Athl Train, 43*(3), 265-274.

Marcotte, T. D., Rosenthal, T. J., Roberts, E., Lampinen, S., Scott, J. C., Allen, R. W., & Corey-Bloom, J. (2008). The contribution of cognition and spasticity to driving performance in multiple sclerosis. *Arch Phys Med Rehabil, 89*(9), 1753-1758.

Marino, M., de Belvis, A., Basso, D., Avolio, M., Pelone, F., Tanzariello, M., & Ricciardi, W. (2013). Interventions to evaluate fitness to drive among people with chronic conditions: Systematic review of literature. *Accid Anal Prev, 50*, 377-396.

Marshall, S., Man-Son-Hing, M., Molnar, F., Hunt, L., & Finestone, H. (2005). An exploratory study on the predictive elements of passing on-the-road tests for disabled persons. *Traffic Inj Prev, 6*(3), 235-239.

Mayhew, D. R., Simpson, H. M., Wood, K. M., Lonero, L., Clinton, K. M., & Johnson, A. G. (2011). On-road and simulated driving: concurrent and discriminant validation. *J Safety Res, 42*(4), 267-275.

McCrory, P., Meeuwisse, W., Aubry, M., Cantu, B., Dvorak, J., Echemendia, R. J., . . . Tator, C. H. (2013). Consensus statement on concussion in sport--the 4th International Conference on Concussion in Sport held in Zurich, November 2012. *Clin J Sport Med, 23*(2), 89-117.

McKee, A. C., Daneshvar, D. H., Alvarez, V. E., & Stein, T. D. (2014). The neuropathology of sport. *Acta Neuropathol, 127*(1), 29-51.

McKnight, A. J., & McKnight, A. S. (2003). Young novice drivers: careless or clueless? *Accid Anal Prev, 35*(6), 921-925.

McMillan, T. M., Teasdale, G. M., & Stewart, E. (2012). Disability in young people and adults after head injury: 12-14 year follow-up of a prospective cohort. *J Neurol Neurosurg Psychiatry, 83*(11), 1086-1091.

Meier, T. B., Bellgowan, P. S., Singh, R., Kuplicki, R., Polanski, D. W., & Mayer, A. R. (2015). Recovery of Cerebral Blood Flow Following Sports-Related Concussion. *JAMA Neurol*. doi: 10.1001/jamaneurol.2014.4778

Michon, J. A. (1985). A critical view of driver behavior models. *Human Bahavior and Traffic Safety, New York*

Michon, J. A. (1989). Explanatory pitfalls and rule-based driver models. *Accid Anal Prev, 21*(4), 341-353.

Milleville-Pennel, I., Pothier, J., Hoc, J. M., & Mathe, J. F. (2010). Consequences of cognitive impairments following traumatic brain injury: Pilot study on visual exploration while driving. *Brain Inj, 24*(4), 678-691.

Nalder, E., Fleming, J., Cornwell, P., Foster, M., Ownsworth, T., Shields, C., & Haines, T. (2012). Recording sentinel events in the life course of individuals with acquired brain injury: a preliminary study. *Brain Inj, 26*(11), 1381-1396.

Neyens, D. M., & Boyle, L. N. (2012). Crash risk factors related to individuals sustaining and drivers following traumatic brain injuries. *Accid Anal Prev, 49*, 266-273.

Niemeier, J. P., Grafton, L. M., & Chilakamarri, T. (2015). Treating persons with traumatic brain injury: history and updates. *N C Med J, 76*(2), 105-110.

Novack, T. A., Banos, J. H., Alderson, A. L., Schneider, J. J., Weed, W., Blankenship, J., & Salisbury, D. (2006). UFOV performance and driving ability following traumatic brain injury. *Brain Inj, 20*(5), 455-461.

Novack, T. A., Labbe, D., Grote, M., Carlson, N., Sherer, M., Arango-Lasprilla, J. C., . . . Seel, R. T. (2010). Return to driving within 5 years of moderate-severe traumatic brain injury. *Brain Inj, 24*(3), 464-471.

Ontario Neurotrauma Fondation. (2013). Guidelines for Concussion/mTBI and Persistant Symptoms: Second Edition.

Ortoleva, C., Brugger, C., Van der Linden, M., & Walder, B. (2012). Prediction of driving capacity after traumatic brain injury: a systematic review. *J Head Trauma Rehabil, 27*(4), 302-313.

Parmet, Y., Borowsky, A., Yona, O., & Oron-Gilad, T. (2015). Driving speed of young novice and experienced drivers in simulated hazard anticipation scenes. *Hum Factors, 57*(2), 311-328. doi: 10.1177/0018720814548220

Pickerill, M. L., & Harter, R. A. (2011). Validity and reliability of limits-of-stability testing: a comparison of 2 postural stability evaluation devices. *J Athl Train, 46*(6), 600-606.

Ponsford, Downing, M. G., Olver, J., Ponsford, M., Acher, R., Carty, M., & Spitz, G. (2014). Longitudinal follow-up of patients with traumatic brain injury: outcome at two, five, and ten years post-injury. *J Neurotrauma, 31*(1), 64-77.

Ponsford, J., Willmott, C., Rothwell, A., Cameron, P., Ayton, G., Nelms, R., . . . Ng, K. T. (1999). Cognitive and behavioral outcome following mild traumatic head injury in children. *J Head Trauma Rehabil, 14*(4), 360-372.

Preece, M. H., Geffen, G. M., & Horswill, M. S. (2013). Return-to-driving expectations following mild traumatic brain injury. *Brain Inj, 27*(1), 83-91.

Preece, M. H., Horswill, M. S., & Geffen, G. M. (2010). Driving after concussion: the acute effect of mild traumatic brain injury on drivers' hazard perception. *Neuropsychology, 24*(4), 493-503.

Rapport, L. J., Bryer, R. C., & Hanks, R. A. (2008). Driving and community integration after traumatic brain injury. *Arch Phys Med Rehabil, 89*(5), 922-930.

Rebar, A. L., Stanton, R., Geard, D., Short, C., Duncan, M. J., & Vandelanotte, C. (2015). A Meta-Meta-Analysis of the effect of physical activity on depression and anxiety in non-clinical adult populations. *Health Psychol Rev*, 1-78. doi: 10.1080/17437199.2015.1022901

Reimer, B., D'Ambrosio, L. A., Coughlin, J. E., Kafrissen, M. E., & Biederman, J. (2006). Using self-reported data to assess the validity of driving simulation data. *Behav Res Methods, 38*(2), 314-324.

Rethorst, C. D., Wipfli, B. M., & Landers, D. M. (2009). The antidepressive effects of exercise: a meta-analysis of randomized trials. *Sports Med, 39*(6), 491-511. doi: 10.2165/00007256-200939060-00004

Rimer, J., Dwan, K., Lawlor, D. A., Greig, C. A., McMurdo, M., Morley, W., & Mead, G. E. (2012). Exercise for depression. *Cochrane Database Syst Rev, 7*, CD004366. doi: 10.1002/14651858.CD004366.pub5

Rohling, M. L., Faust, M. E., Beverly, B., & Demakis, G. (2009). Effectiveness of cognitive rehabilitation following acquired brain injury: a meta-analytic re-examination of Cicerone et al.'s (2000, 2005) systematic reviews. *Neuropsychology, 23*(1), 20-39. doi: 10.1037/a0013659

Ross, V., Jongen, E. M., Wang, W., Brijs, T., Brijs, K., Ruiter, R. A., & Wets, G. (2014). Investigating the influence of working memory capacity when driving behavior is combined with cognitive load: An LCT study of young novice drivers. *Accid Anal Prev, 62*, 377-387. doi: 10.1016/j.aap.2013.06.032

Ruff, R. M., Iverson, G. L., Barth, J. T., Bush, S. S., & Broshek, D. K. (2009). Recommendations for diagnosing a mild traumatic brain injury: a National Academy of Neuropsychology education paper. *Arch Clin Neuropsychol, 24*(1), 3-10.

Rutland-Brown, W., Langlois, J. A., Thomas, K. E., & Xi, Y. L. (2006). Incidence of traumatic brain injury in the United States, 2003. *J Head Trauma Rehabil, 21*(6), 544-548.

Ryu, W. H., Feinstein, A., Colantonio, A., Streiner, D. L., & Dawson, D. R. (2009). Early identification and incidence of mild TBI in Ontario. *Can J Neurol Sci, 36*(4), 429-435.

Sabaté, E. (2003). Adherence to Long-Term Therapies: Evidence for Action. *World Health Organization*, 211.

Sady, M. D., Vaughan, C. G., & Gioia, G. A. (2014). Psychometric characteristics of the postconcussion symptom inventory in children and adolescents. *Arch Clin Neuropsychol, 29*(4), 348-363.

Schanke, A. K., Rike, P. O., Molmen, A., & Osten, P. E. (2008). Driving behaviour after brain injury: a follow-up of accident rate and driving patterns 6-9 years post-injury. *J Rehabil Med, 40*(9), 733-736.

Schmidt, M. (1996). Rey Auditory Verbal Learning Test *Los Angeles: Western Psycho-logical Services.*

Schneider, K. J., Iverson, G. L., Emery, C. A., McCrory, P., Herring, S. A., & Meeuwisse, W. H. (2013). The effects of rest and treatment following sport-related concussion: a systematic review of the literature. *Br J Sports Med, 47*(5), 304-307.

Schneiders, A. G., Sullivan, S. J., Gray, A. R., Hammond-Tooke, G. D., & McCrory, P. R. (2010). Normative values for three clinical measures of motor performance used in the neurological assessment of sports concussion. *J Sci Med Sport, 13*(2), 196-201. doi: 10.1016/j.jsams.2009.05.004

Schultheis, M. T., Matheis, R. J., Nead, R., & DeLuca, J. (2002). Driving behaviors following brain injury: self-report and motor vehicle records. *J Head Trauma Rehabil, 17*(1), 38-47.

Schultheis, M. T., & Rizzo, A. A. (2001). The Application of Virtual reality Technology in Rehabilitation *Rehabilitation Psychology 46*(3), 296-311.

Schultheis, M. T., Simone, L. K., Roseman, E., Nead, R., Rebimbas, J., & Mourant, R. (2006). Stopping behavior in a VR driving simulator: a new clinical measure for the assessment of driving. *Conf Proc IEEE Eng Med Biol Soc, 1*, 4921-4924.

Scialfa, C. T., Borkenhagen, D., Lyon, J., Deschenes, M., Horswill, M., & Wetton, M. (2012). The effects of driving experience on responses to a static hazard perception test. *Accid Anal Prev, 45*, 547-553. doi: 10.1016/j.aap.2011.09.005

Scott, H., Hall, L., Litchfield, D., & Westwood, D. (2013). Visual information search in simulated junction negotiation: gaze transitions of young novice, young experienced and older experienced drivers. *J Safety Res, 45*, 111-116. doi: 10.1016/j.jsr.2013.01.004

Scottish Intercollegiate Guideline Network. (2013). Brain injury rehabilitation in adults *Edinburgh*(130).

Selassie, A. W., Wilson, D. A., Pickelsimer, E. E., Voronca, D. C., Williams, N. R., & Edwards, J. C. (2013). Incidence of sport-related traumatic brain injury and risk factors of severity: a population-based epidemiologic study. *Ann Epidemiol, 23*(12), 750-756. doi: 10.1016/j.annepidem.2013.07.022

Selassie, A. W., Zaloshnja, E., Langlois, J. A., Miller, T., Jones, P., & Steiner, C. (2008). Incidence of long-term disability following traumatic brain injury hospitalization, United States, 2003. *J Head Trauma Rehabil, 23*(2), 123-131.

Shechtman, O., Classen, S., Awadzi, K., & Mann, W. (2009). Comparison of driving errors between on-the-road and simulated driving assessment: a validation study. *Traffic Inj Prev, 10*(4), 379-385.

Silverberg, N. D., & Iverson, G. L. (2013). Is rest after concussion "the best medicine?": recommendations for activity resumption following concussion in athletes, civilians, and military service members. *J Head Trauma Rehabil, 28*(4), 250-259.

Smith, A. (1982). Symbol Digit Modalities Test (SDMT) *Manual (Rev.). Los Angeles: Western Psychological Services.*

Sours, C., Zhuo, J., Roys, S., Shanmuganathan, K., & Gullapalli, R. P. (2015). Disruptions in Resting State Functional Connectivity and Cerebral Blood Flow in Mild Traumatic Brain Injury Patients. *PLoS One, 10*(8), e0134019. doi: 10.1371/journal.pone.0134019

Spielberger, C. D. (2010). State-Trait Anxiety Inventory. *Corsini Encyclopedia of Psychology. 1.*

Svaldi, D. O., Joshi, C., Robinson, M. E., Shenk, T. E., Abbas, K., Nauman, E. A., . . . Talavage, T. M. (2015). Cerebrovascular reactivity alterations in asymptomatic high school football players. *Dev Neuropsychol, 40*(2), 80-84. doi: 10.1080/87565641.2014.973959

Tamietto, M., Torrini, G., Adenzato, M., Pietrapiana, P., Rago, R., & Perino, C. (2006). To drive or not to drive (after TBI)? A review of the literature and its implications for rehabilitation and future research. *NeuroRehabilitation, 21*(1), 81-92.

Tan, C. O., Meehan, W. P., 3rd, Iverson, G. L., & Taylor, J. A. (2014a). *Cerebrovascular regulation, exercise, and mild traumatic brain injury*: Neurology. 2014 Oct 1. pii: 10.1212/WNL.

Tan, C. O., Meehan, W. P., 3rd, Iverson, G. L., & Taylor, J. A. (2014b). Cerebrovascular regulation, exercise, and mild traumatic brain injury. *Neurology, 83*(18), 1665-1672. doi: 10.1212/wnl.0000000000000944

Teasdale, G., & Jennett, B. (1974). Assessment of coma and impaired consciousness. A practical scale. *Lancet, 2*(7872), 81-84.

Teasdale, G., & Jennett, B. (1976). Assessment and prognosis of coma after head injury. *Acta Neurochir, 34*(1-4), 45-55.

Thurman, D. J. (2014). The Epidemiology of Traumatic Brain Injury in Children and Youths: A Review of Research Since 1990. *J Child Neurol.* doi: 10.1177/0883073814544363

Tomaszczyk, J. C., Green, N. L., Frasca, D., Colella, B., Turner, G. R., Christensen, B. K., & Green, R. E. (2014). Negative neuroplasticity in chronic traumatic brain injury and implications for neurorehabilitation. *Neuropsychol Rev, 24*(4), 409-427. doi: 10.1007/s11065-014-9273-6

Tsaousides, T., & Gordon, W. A. (2009). Cognitive rehabilitation following traumatic brain injury: assessment to treatment. *Mt Sinai J Med, 76*(2), 173-181. doi: 10.1002/msj.20099

Underwood, G. (2013). On-road behaviour of younger and older novices during the first six months of driving. *Accid Anal Prev, 58*, 235-243. doi: 10.1016/j.aap.2012.03.019

van Zomeren, A. H., Brouwer, W. H., & Minderhoud, J. M. (1987). Acquired brain damage and driving: a review. *Arch Phys Med Rehabil, 68*(10), 697-705.

Vanderploeg, R. D., Curtiss, G., Luis, C. A., & Salazar, A. M. (2007). Long-term morbidities following self-reported mild traumatic brain injury. *J Clin Exp Neuropsychol, 29*(6), 585-598.

Villamar, M. F., Santos Portilla, A., Fregni, F., & Zafonte, R. (2012). Noninvasive brain stimulation to modulate neuroplasticity in traumatic brain injury. *Neuromodulation, 15*(4), 326-338. doi: 10.1111/j.1525-1403.2012.00474.x

Vrkljan, B. H., McGrath, C. E., & Letts, L. J. (2011). Assessment tools for evaluating fitness to drive: a critical appraisal of evidence. *Can J Occup Ther, 78*(2), 80-96.

Wang, Y., Mehler, B., Reimer, B., Lammers, V., D'Ambrosio, L. A., & Coughlin, J. F. (2010). The validity of driving simulation for assessing differences between in-vehicle informational interfaces: A comparison with field testing. *Ergonomics, 53*(3), 404-420. doi: 10.1080/00140130903464358

Wechsler, D. (2003). Wechsler Intelligence Scale for Children-WISC-IV. *Pychological Corporation.*

Wechsler, D. (2008). Wechsler adult intelligence scale–Fourth Edition (WAIS–IV). . *San Antonio, TX: NCS Pearson.*

Willer, B., & Leddy, J. J. (2006). Management of concussion and post-concussion syndrome. *Curr Treat Options Neurol, 8*(5), 415-426.

Wise, E. K., Hoffman, J. M., Powell, J. M., Bombardier, C. H., & Bell, K. R. (2012). Benefits of exercise maintenance after traumatic brain injury. *Arch Phys Med Rehabil, 93*(8), 1319-1323.

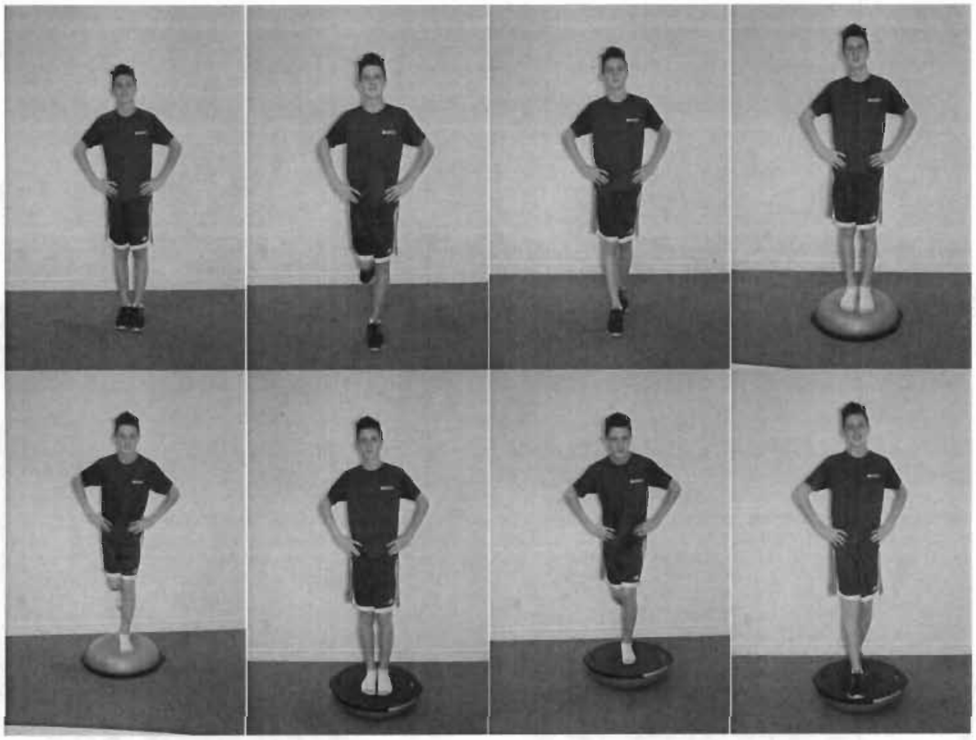
World Health Organisation. (2006). Neurological disorders: public health challenges. *WHO library*(140).

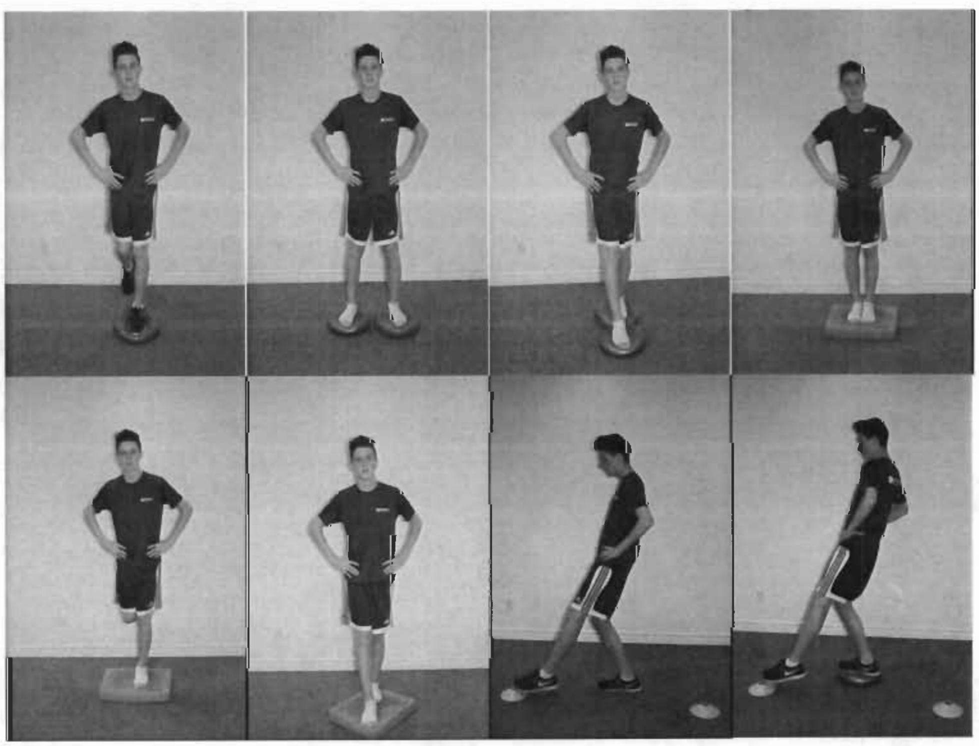
Yuen, H. K., Brooks, J. O., Azuero, A., & Burik, J. K. (2012). Certified driver rehabilitation specialists' preferred situations for driving simulator scenarios. *Am J Occup Ther, 66*(1), 110-114.

Zemek, R., Duval, S., Dematteo, C., & ... (2014). Guideline for Diagnosing and Managing Pediatric Concussion *Toronto, ON: Ontario Neurotrauma Foundation, First edition June 2014.*

ANNEXE A

Therapeutic exercises





Université du Québec à Trois-Rivières

CERTIFICAT D'ÉTHIQUE DE LA RECHERCHE

RAPPORT DU COMITÉ D'ÉTHIQUE :

Le comité d'éthique de la recherche, mandaté à cette fin par l'Université, certifie avoir étudié le protocole de recherche :

Titre du projet : Entraînement des capacités à conduire chez des individus ayant subi un traumatisme craniocérébral

Chercheurs : Philippe Fait

Département des sciences de l'activité physique

Organismes : FQRSC-SAAQ-FRSQ(bourse postdoctorale)

et a convenu que la proposition de cette recherche avec des êtres humains est conforme aux normes éthiques.

PÉRIODE DE VALIDITÉ DU PRÉSENT CERTIFICAT :

Date de début : 17 décembre 2012 Date de fin : 17 décembre 2013

COMPOSITION DU COMITÉ :

Le comité d'éthique de la recherche de l'Université du Québec à Trois-Rivières est composé des catégories de personnes suivantes, nommées par le conseil d'administration :

- six professeurs actifs ou ayant été actifs en recherche, dont le président et le vice-président;
- une personne membre ou non de la communauté universitaire, possédant une expertise dans le domaine de l'éthique
- un(e) étudiant(e) de deuxième ou de troisième cycle;
- un technicien de laboratoire;
- une personne ayant une formation en droit et appelée à siéger lorsque les dossiers le requièrent;
- une personne extérieure à l'Université;
- un secrétaire provenant du Décanat des études de cycles supérieurs et de la recherche ou un substitut suggéré par le doyen des études de cycles supérieurs et de la recherche.

SIGNATURES :

L'Université du Québec à Trois-Rivières confirme, par la présente, que le comité d'éthique de la recherche a déclaré la recherche ci-dessus mentionnée entièrement conforme aux normes éthiques.

Hélène-Marie Thérien
Présidente du comité

Fanny Longpré
Secrétaire du comité

Date d'émission : 18 décembre 2012

N° du certificat : CER-13-187-09.01

DECSR

Université du Québec à Trois-Rivières

CERTIFICAT D'ÉTHIQUE DE LA RECHERCHE

RAPPORT DU COMITÉ D'ÉTHIQUE :

Le comité d'éthique de la recherche, mandaté à cette fin par l'Université, certifie avoir étudié le protocole de recherche :

Titre du projet : Efficacité d'une intervention en réadaptation active chez une population pédiatrique ayant une récupération atypique suite à un traumatisme craniocérébral léger

Chercheurs : Sarah Imhoff

Département des sciences de l'activité physique

Organismes : Fonds de recherche du Dr Philippe Fait

et a convenu que la proposition de cette recherche avec des êtres humains est conforme aux normes éthiques.

PÉRIODE DE VALIDITÉ DU PRÉSENT CERTIFICAT :

Date de début : 02 octobre 2013 Date de fin : 02 octobre 2014

COMPOSITION DU COMITÉ :

Le comité d'éthique de la recherche de l'Université du Québec à Trois-Rivières est composé des catégories de personnes suivantes, nommées par le conseil d'administration :

- six professeurs actifs ou ayant été actifs en recherche, dont le président et le vice-président;
- une personne membre ou non de la communauté universitaire, possédant une expertise dans le domaine de l'éthique
- un(e) étudiant(e) de deuxième ou de troisième cycle;
- un technicien de laboratoire;
- une personne ayant une formation en droit et appelée à siéger lorsque les dossiers le requièrent;
- une personne extérieure à l'Université;
- un secrétaire provenant du Décanat de la recherche et de la création ou un substitut suggéré par le doyen de la recherche et de la création.

SIGNATURES :

L'Université du Québec à Trois-Rivières confirme, par la présente, que le comité d'éthique de la recherche a déclaré la recherche ci-dessus mentionnée entièrement conforme aux normes éthiques.

Hélène-Marie Thérien
Présidente du comité

Marie-Eve St-Germain
Secrétaire du comité

Date d'émission : 02 octobre 2013

N° du certificat : CER-13-194-07.11

DECSR