BRAIN MAPPING
AN ENCYCLOPEDIC REFERENCE

Volume 2
Anatomy and Physiology
Systems
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Neural Correlates of Motor Deficits in Young Patients with Traumatic Brain Injury

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Glossary

MRI technology that measures brain activity during tasks by
Diffuse axonal injury (DAI) Widespread damage to white matter tracts and projections to the cortex after traumatic brain injury. 

Resting-state fMRI (rs-fMRI) A method of functional brain imaging that can be used to evaluate regional interactions that occur when a subject is not performing an explicit task.

Diffusion tensor imaging (DTI) An MRI technique that enables the measurement of the restricted diffusion of water in tissue in order to produce neural tract images.

Traumatic brain injury (intracranial injury) Injury that occurs when an external force traumatically injures the brain.

Functional magnetic resonance imaging or functional MRI (fMRI) A functional neuroimaging procedure using (such as a traffic accident, fall, or sport injury).

Motor Deficits in Young Patients with Traumatic Brain Injury

remains frequently impaired (Brink et al., 1970; Van der Schaaf et al., 1997). Rossi and Sullivan (1996) found deficits in
Acquired brain injury (ABI) is one of the leading causes of death strength, agility, and coordination about 4 years after injury, or permanent disability in children and adolescents in the which limited the children’s participation in sports and other United States. Approximately 200 000 patients with pediatric physical activities. Other studies reported low performance on brain injury are hospitalized each year, and of these children, fine motor tasks involving upper-limb speed and dexterity 30 000 suffer permanent disability (Guyer & Ellers, 1990). more than 1 year after TBI (Asikainen et al., 1999; Chaplin et al., 1993; Wallen et al., 2001). Few studies, however, have the true burden of ABI, as many individuals with milder injuries used instrumented quantitative measures to assess the recovery are often unknown to the medical system (Langlois et al., 2006). ABI can result from multiple causes, including trauma lyses of motor behavior can objectify performance levels that (motor vehicle accidents, bicycle accidents, falls, and sport are not clearly visible with the naked eye and may contribute to injuries), central nervous system infections, noninfectious dis-
both evaluation of rehabilitation and a better understanding of orders (epilepsy, hypoxia/ischemia, and genetic/metabolic the relationship between brain injury and ensuing deficits. disorders), tumors, and vascular abnormalities (Atabaki, Therefore, in our previous studies (Caeyenberghs et al., 2007). Although there are many causes of ABI in children, 2009a, 2009b; 2010a, 2010b; see Table 1), impairments of traumatic brain injury (TBI) is by far the most common. The relevant functional motor tasks, that is, postural control and severity of such injuries may range from ‘mild,’ that is, a brief eye–hand coordination, were assessed with instrumented mea-change in mental status or consciousness, to ‘severe,’ that is, an sures in children with ABI. Both functions are essential for many extended period of unconsciousness or amnesia after the injury. activities of daily living. Moreover, both tasks reveal different More than 450 000 children under the age of 14 years are aspects of motor performance and rely on very different brain admitted to the emergency department each year for TBI in the structures, underscoring their complementarity.

United States (Langlois et al., 2006). Although considerable First, the interactive technology and clinically proven pro-
strides have been made in decreasing overall TBI-related mor-
tocols of the NeuroCom system allowed us to objectively and
mortality by the application of evidence-based medicine, many
systematically assess balance control (Caeyenberghs et al.,
individuals develop chronic problems, often resulting in life-
2010a, 2010b). As part of the EquiTest system, the Sensory
Organization Test (SOT) protocol systematically disrupted the
The clinical outcome in pediatric TBI is highly variable but
sensory selection processes (i.e., somatosensory, visual inputs, or
often includes persistent cognitive problems such as attention
both) while measuring a subject’s ability to maintain equilib-
rium. Six sensory conditions evaluated the relative contributions
finding difficulties, impaired executive function, behavioral
of vision, vestibular, and somatosensory inputs in balance func-
disinhibition, and emotional lability (Taylor, 2004; Yeates &
tion. In condition 1, all three sensory systems were operational
Taylor, 2005). Motor disabilities are often less obvious in
while the participant stood on a fixed platform with eyes open,
children with TBI than in children with cerebral palsy and are and a baseline measure of stability was obtained. Condition 2 sometimes considered a less pervasive problem than cognitive was the same as condition 1, except that the eyes were closed. deficits (Bowen et al., 1997; Emanuelson et al., 1998). Never-Condition 3 was similar to condition 1 but the visual surround theless, several studies reported long-lasting deficits in motor moved to track the participant’s sway, which provided inaccurate proficiency of children after TBI, which can lead to significant orientation cues. In condition 4, the subject stood with the eyes functional losses. The majority of children sustaining severe open and the visual surround fixed but the platform moved in

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INTRODUCTION TO SYSTEMS | Neural Correlates of Motor Deficits in Young Patients with Traumatic Brain Injury

Table 1
Overview of the different studies

Mean age at

N

Description of the participants and methods

Mean age

injury

Caeyenberghs et al.

28 ABI and 28

Traumatic brain injury (N ¼ 14), surgery (N ¼ 6), vascular disease

11 years 9

9 years 4

(2009a)

controls

(N ¼ 6), infections (N ¼ 2)

months

months

Tracking tasks (feedback and feedforward)

Caeyenberghs et al.

9 TBI and 17

Traumatic brain injury (no focal lesions)
12 years
9 years 10

(2009b)

controls
Task-related fMRI (coordination task)
8 months
months

Caeyenberghs et al.
12 TBI and 14
Traumatic brain injury
14 years
10 years 6

(2010a)

controls
Instrumented motor task: SOT protocol of the NeuroCom
8 months
months
Diffusion tensor imaging

Caeyenberghs et al.
17 TBI and 14
Traumatic brain injury

14 years

10 years

(2010b)

controls

Tracking task (feedforward)

months

8 months

Diffusion tensor imaging

Caeyenberghs et al.

12 TBI and 17

Traumatic brain injury

14 years

10 years

(2012)

control

Diffusion tensor imaging and graph analyses

8 months

months

Caeyenberghs et al.,
12 TBI and 28
Traumatic brain injury (no focal lesions)
14 years 4
10 years
(in press)
controls
Resting-state fMRI
months
8 months
response to his/her sway such that the ankle joints did not bend
performing the dynamic tracking task, in which both spatial
in response to the sway, providing inaccurate proprioceptive
and temporal constraints had to be dealt with. As compared
input to the brain. Condition 5 was identical to condition 4
with the control children, the children with brain injury were
except that the eyes were now closed, such that only the vestib-
less successful in continuously keeping the cursor inside the
ular system was fully operational. Condition 6 was the same as
target, reflected in a shorter duration within the target, a larger
condition 4 except that the visual surround moved in response to
distance (and variability of this distance) between the centers
the participant’s sway, and thus, both vision and proprioception
of cursor and target, and more feedback-based corrections
were compromised, leaving only the vestibular system as a reli-
able source. The subject’s sway was calculated from the maxi-
 Obtained results raised the question whether the structural
mum anterior and posterior centers of gravity displacements,
changes in the brain of TBI children are predictive of motor
occurring over the 20 s trial period. Our behavioral results
behavior deficits, as discussed in the next section.
revealed that the TBI group scored generally lower than the
control group on the SOT, especially in conditions where visual
and vestibular inputs must be relied upon to produce stability.
Structural Integrity of the Brain and Its Relation
The mean composite SOT score (average across all six condi-
tions) also differed significantly between the TBI patients and the
controls. The lower scores of the subjects with TBI indicate
Traditional
imaging techniques, such as computerized tomography and conventional magnetic resonance imaging control subjects. (MRI), have proved to be highly effective in identifying macroscopic lesions, which is a necessary component in managing acute TBI (Levin, 2003; Povlishock & Katz, 2005). However, these techniques have marked limitations in assessing micro-movements accurately (Caeyenberghs et al., 2009a, 2009b). In scopic lesions and cerebral physiology, such as those associated with diffuse axonal injury (DAI), which is widespread, the static visuomotor task, a computerized version of the flower trail task of the Movement Assessment Battery for Child-damage to axons including white matter tracts and projections
Children was used. Children traced a flower as accurately as possible to the cortex. Diffusion tensor imaging (DTI), however, generates images by taking advantage of the variability of both the speed constraints. In contrast, the dynamic task required faster speed and direction of water diffusion in vivo ([Le Bihan et al., 2001]). DTI is based on the characteristics of myelin sheaths and cell membranes of white matter tracts that restrict the movement of water molecules. As a result, water molecules moved faster parallel to the major axis of nerve fibers rather than perpendicular to them. This characteristic, which is referred to as anisotropic diffusion, is most commonly characterized by a metric called fractional anisotropy (FA). It is deter-
exception of one dependent variable (number of errors), no
mined by several factors including the thickness of the myelin
significant group differences were found for the kinematic-
sheath and axons and the organization of the fibers and prop-
dependent variables. Thus, no striking differences were
erties of the intracellular and extracellular space around the
observed between groups in performing precise tracing. In
axon. FA ranges from 0 to 1, where 0 represents maximal
contrast, children with brain injury showed clear problems in
isotropic diffusion (e.g., free diffusion in all directions) and 1


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represents maximal anisotropic diffusion, that is, movement
various extents in young TBI patients and may have important
parallel to the major axis of a white matter tract. Isotropic
consequences for the final motor outcome of these patients.
diffusion of water in multiple directions is measured by the
The observed decrease of FA in our study was mediated by
mean diffusivity (MD) or ‘apparent diffusion coefficient.’ MD
the combined effects of AD and RD increases. Specifically, we is often (but not always) negatively correlated with FA. Lower found increased RD and AD in the TBI group for the whole FA is often observed in TBI, especially in regions with diffuse brain and for specific regions of interest, possibly reflecting axonal injuries, and MD is higher in TBI (Huisman et al., 2004; damage to both the myelin and axons (e.g., Arfanakis et al., Levin, 2003). While the summary parameters, FA and MD, are commonly reported, the underlying eigenvalues hold addi-
et al., 2007). Kraus and colleagues (2007) also noted reduced tional valuable information as they may be selectively affected FA and elevated AD and RD in all of their 13 ROIs in chronic with certain pathological processes (Song et al., 2002). Axial patients sustaining moderate to severe TBI. In patients with diffusivity (AD) reflects diffusivity parallel to axonal fibers. mild TBI, FA was reduced in 3 of 13 ROIs (i.e., the corticospinal Increases in AD are thought to reflect pathology of the axon tract, sagittal stratum and superior longitudinal fasciculus), itself, such as from trauma. Radial diffusivity (RD) reflects whereas AD was only elevated in 2 of the ROIs (i.e., the sagittal
diffusivity perpendicular to axonal fibers and appears to be stratum and superior longitudinal fasciculus). These findings more strongly correlated with myelin abnormalities, either suggest a continuum of widespread neural changes in moder-
dysmyelination or demyelination. In adults, DTI has been 
ate to severe TBI affecting tissue organization, myelin, and successfully employed in several patient populations, includ-
axonal integrity. Definite interpretation of these abnormalities ing those with stroke (e.g., Sotak, 2002), multiple sclerosis requires a comprehensive assessment of the white matter, (e.g., Bammer et al., 2000; Filippi & Inglese, 2001; Fox, 2008; which is the basis of the ‘tractometry’ philosophy introduced Ge et al., 2005), epilepsy (e.g., Luat & Chugani, 2008; Widjaja recently (de Santis et al., 2014). This method combines macro-
& Raybaud, 2008), Alzheimer’s disease (e.g., Hess, 2009; molecular measurements from optimized magnetization trans-
Stebbins & Murphy, 2009), and brain tumors (e.g., Mechtler, fer imaging (Cercignani & Alexander, 2006), multicomponent 2009; Wieshmann et al., 2000). Most DTI studies in TBI have T2 species from relaxometry (Deoni et al., 2008), and axonal focussed on the adult population (for an excellent review, see

along specific white matter pathways, providing a comprehensive assessment of multiple microstructural metrics. Our studies (see Table 1) used DTI-based maps for the evaluation of various sensorimotor tracts and cerebral white matter regions in an attempt to reveal the degree of structural patients, the question emerges whether this structural disconnection deficit has direct functional consequences. In our studies (Caeyenberghs et al., 2010a, 2010b, 2011), injury in both patients, including the corpus callosum, brain stem, internal efferent and afferent pathways was found to correlate with capsule, corticospinal tract, cerebral peduncle, cerebellar reduced motor performance in the TBI group, but not in the peduncles, and anterior corona radiate, with several regions/tracts also demonstrating higher MD. There is some degree of example, the number of velocity peaks during the dynamic tracking.
overlap between those brain regions that are particularly vul-
task was significantly correlated to mean FA in the anterior
nerable to injury in TBI and the structures believed to support
limb of the internal capsule (to a large extent occupied by the
motor function. For example, shearing injuries in TBI occur
corticospinal tract), indicating that less fluent tracking was
most commonly near the basal ganglia, superior cerebellar
related to lower FA. The equilibrium scores of the NeuroCom
peduncles, corpus callosum, internal capsule, and brain stem
SOT test (see earlier) was related to FA of the cerebellum, an
(Yeates, 2000). Moreover, decreased FA has been found in the important
structure for balance control. Hence, higher balance
TBI group in sensory cortex pathways, that is, posterior thal-
levels were associated with a higher white matter anisotropy.
lamic radiation and optic radiation. This suggests that white
Motor indices, though not fully investigated in the head injury
matter projections to or from sensory cortices rather than
literature, have previously been reported to be associated with
classical pyramidal motor tracts may play an important role
DTI measures in other disorders. For example, DTI metrics
in the pathophysiology of motor disability in some TBI chil-
are correlated with tests of upper-limb function in patients
dren. Compared to the motor system (corticospinal tract),
with congenital hemiplegia and chronic stroke patients
there has been limited DTI-based literature on the specific
(Bleyenheuft et al., 2007; Schaechter et al., 2009). Unfortu-
sensory pathways (Kamali et al., 2009). Few DTI studies have nately, studies
correlating DTI parameters with kinematic mea-
assessed the sensory system in clinical conditions. For example,
sures of motor performance are scarce. The importance of the
in periventricular leukomalacia, DTI studies have demon-
changes in diffusivity in our study was also highlighted by the
strated decreased thalamocortical sensory connections, which
significant correlations between diffusivity and the motor
are responsible for the spasticity owing to impairment of inhib-
scores. Increases in MD, AD, and RD were associated with
itory function (Hoon et al., 2002, 2009; Nagae et al., 2007).
poor scores on the dynamic tracking task and the NeuroCom
This pattern of observed impairment of sensory WM pathways
balance task (see earlier). Additional analyses showed that the
corresponds well with our functional MRI (fMRI) study, indi-
FA of the cerebellum was the most critical DTI variable provid-
cating that successful motor coordination in young TBI patients is associated with enhanced activity in somatosensory and better motor skills. These findings emphasize the vulnerability of the cerebellum to TBI and suggest the cerebellum as a target for therapeutic intervention.


It is important to note that no significant correlations were found between the amount of global WM neuropathology and the coordinated hand–foot movements. However, increased activation in brain regions was observed in the TBI group as compared with the control par-
This observation suggests that injury to participants. No evidence was obtained for decreased activation specific WM tracts and regions is probably responsible for the relative to controls. More specifically, TBI children showed motor deficits seen in patients with moderate to severe TBI. For higher activation in the precuneus, which was hypothesized example, FA of the optic radiation and cerebellar peduncles to reflect increased attentional deployment for task performance significantly contributed to the prediction of the visuomotor performance. There is increasing agreement that this area is more performance of the dynamic eye–hand coordination task closely related to cognitive than to motor processes. The pre-cuneus is involved in self-referential processing, imagery, and above and beyond whole-brain FA (Caeyenberghs et al., 2010a, 2010b). Thus, the specific motor deficits are often memory (Cavanna & Trimble, 2006), and its deactivation is related to FA in task-specific WM structures. The absence of a associated with anesthetic-induced loss of consciousness relationship between whole-brain anisotropy and behavioral (Alkire et al., 2008). These functional aspects can be explained measures is inconsistent with previous studies (Kraus et al.,
on the basis of its high centrality in the cortical network (Kumar et al., 2009), which have reported significant (Bullmore & Sporns, 2009; Gong et al., 2009; Hagmann)

relationships between cognition and WM load. Previous work (Iturria-Medina et al., 2007). has also shown total WM FA to be correlated with clinical

Furthermore, additional activation was shown in posterior markers of severity in a cohort of adolescents and adults with cerebellar regions and somatosensory areas. The postcentral TBI (ages 11–57) (Benson et al., 2007). Levin and colleagues (2008) also demonstrated a relationship between a composite in the integration of somatosensory information to guide FA score, obtained 3 months after injury, and both clinical motor actions (e.g., Ashe & Georgopoulos, 1994; Rizzolatti et al., 1998; Scott et al., 1997). The cerebellum is specifically known to be involved during ipsilateral coordination of different spread cortical and subcortical networks than the motor system effectors (Debaere et al., 2001, 2004; Heuninckx et al., 2007).
tem, which is likely the reason why global WM load correlates
2005). Activation of the posterior cerebellum as compared
with cognitive function but not with motor function. Finally,
with the anterior cerebellum is more prominent with higher
these differences could also reflect the developmental stages of
task complexity levels and has previously been associated with
the subjects (children/adolescents vs. adults) and severity of
correction of timing adjustment errors. Overall, the findings of
the patient group (mild vs. moderate/severe).
this study suggest that TBI is associated with a shift along the
The aforementioned correlations between brain white mat-
continuum from automatic to more controlled information
ter structure and behavior, and more specifically between FA
processing for movement generation, as reflected by more
and motor deficits in a young TBI group, are of major interest
pronounced somatosensory processing and increased cogni-
for improving prediction of motor outcome in TBI patients
tive effort. Future studies are also needed to clarify both the
and may constitute a potential (bio)marker for therapeutic
short- and long-term effects of neural processing in TBI with

interventions.
respect to other motor tasks besides hand–foot coordination, because of the possibility that TBI may result in a generalized pattern of overactivation in the brain, rather than over-activation specific to hand–foot coordination. We found Brain Function and Compensatory Mechanisms group differences in activation in some regions outside of the motor network but were unable to determine if these areas are recruited as compensatory mechanisms (that are directly asso-
Here, we focus on changes in brain function underlying motor associated with better motor task performance) or as part of a behavior in young patients with TBI. We used task-related fMRI generalized pattern of overactivation.
to compare brain activation patterns of TBI children with Brain activation changes following adult TBI have been controls during the performance of cyclical hand and foot reported in previous functional imaging studies using simple movements across different levels of coordinative complexity motor tasks. In contrast to our work, Prigatano and colleagues
A TBI (N = 9, only DAI (2004) found lower bilateral frontal activation on the Halstead patients) group and a control group (N = 17) were scanned finger tapping test versus rest in seven severe chronic-phase TBI patients as compared with eight healthy noninjured comparison subjects, although this finding was only significant more ‘difficult’ nonisodirectional mode. Performance on the for right-handed tapping. Performance was matched across coordination tasks during scanning was similar between groups. Three of the patients had focal lesions by history.

The overall pattern of brain activation across the Lotze and colleagues (2006) showed also diminished fMRI signal change in the motor cortical network (contralateral using the same task. Comparing our results to findings of primary sensorimotor cortex, contralateral dorsal premotor Heuninckx et al. (2005, 2010) in young and older adults cortex, and SMA) in patients with moderate to severe TBI.
revealed activation in similar brain regions including the contra-
(N = 34) performing unilateral fist clenching motions. These tralateral primary sensorimotor hand and foot areas, supple-
imaging studies with adults suggest that the neural circuitry mentary motor area, supramarginal gyrus, temporal gyrus, supporting motor control is altered after a brain injury, but it is.


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unclear if this holds true for pediatric TBI and for other tasks. future studies employing multiple conditions that vary in task Furthermore, there is some inconsistency among the func-
difficulty are needed to distinguish them properly. tional imaging studies in that some show evidence for

The finding that neural activation is altered following pedi-
overactivation, whereas others show underactivation in TBI. atric TBI during coordination tasks has promising clinical

Our findings of overactivation are consistent with fMRI implications. Persistent changes in neural mechanisms for working memory studies in adults with TBI (Christodoulou)
years following childhood TBI suggest that motor function

et al., 2001; McAllister et al., 1999, 2001) and in children with should continue to be assessed in the chronic phase of TBI.

TBI. Newsome et al. (2007, 2008), Karunanayaka et al. (2007), Kramer et al. (2008) each used fMRI to explore neural reorganization after TBI in children and adolescents. It is difficult

Analyses of Structural and Functional Connectivity
to make direct comparisons between these studies because of differences in the experimental paradigms used. These vary from working memory tasks (N-back task), attention tasks

Our previous discussed studies in TBI patients have related (continuous performance task), interlimb coordination tasks motor functioning to structural and functional properties of (our study), to language tasks (verb generation paradigm). The specific brain regions. However, the drawback of these regional distributed networks involved in each task will vary, and thus, analyses of brain structure and function is that they do not brain activation differences in each experiment will differ.

reveal information about how the information is conveyed

However, taking this into account, there appears to be clear
across the different brain regions of a network (Hagmann et al., 2008; Sporns et al., 2005).

children during a variety of tasks.

Resting-state fMRI (rs-fMRI) is a method of functional brain imaging that relies on measuring low-frequency fluctuations significant correlations for all subjects between the blood oxy-
(LFFs, <0.1 Hz) of BOLD signals and calculating functional gen level-dependent (BOLD) signal activation and perfor-
connectivity between brain regions based on statistical depen-
dencies between intrinsic BOLD signal oscillations in these Scale (GSC) score. Increased activation in many areas of the regions (for a review, see Fox & Greicius, 2010). This (slightly) language circuitry corresponded with poorer performance and newer approach to functional imaging is still hobbled by a low more severe injuries (lower GSC scores). In contrast, Kramer SNR but has the distinct clinical advantages of (1) being easy to
et al. (2008) found that activation in the anterior cingulate, perform in nonacademic imaging centers and (2) allowing
visual association areas (e.g., BA 19), and precuneus was positively related to task performance after controlling for group status. There is an inconsistency in these patterns of correlations across studies (and hence task paradigms), in that a higher level of brain activation is not always associated with more, we applied ‘functional connectivity density mapping,’ a voxel-wise data-driven method that calculates individual functional connectivity maps to measure both short- (implicated in functional specialization) and long-range (implicated in functional integration) FCDs (Tomasi & Volkow, 2010). Between-group maps noted significantly decreased long-range FCD in
with larger samples are needed to examine group differences in the DAI group in frontal and subcortical regions and significantly increased short-range FCD in the frontal regions and left inferior parietal and cerebellar lobules. These findings suggest that long-range connections may be more vulnerable to DAI than short-range connections. Moreover, higher values of short-range FCD may suggest adaptive mechanisms in the McAllister and colleagues (2001) suggested two possible neural mechanisms DAI group. Finally, lower balance levels on the SOT test in patients with DAI were associated with a lower long-range FCD differences in capacity or allocation of neural resources. Specifically, there may be a decrease in overall attentional capacity in left putamen and cerebellar vermis.

In another study (Caeyenberghs et al., 2012), we used DTI-in young patients with TBI, rendering the coordination task
based fiber tractography to reconstruct the human brain white matter networks of a group of young TBI patients and a group perform at behavioral levels comparable to controls. Activation of control participants, followed by a graph theoretical analysis in the precuneus may be specifically augmented in young patients with TBI as a compensatory mechanism. Alternatively, abstract way as a set of ‘nodes,’ defined by anatomical regions subtle deficits in frontal executive functions may have rendered in the cortex, and ‘edges,’ which reflect structural connection the young patients with TBI less able to efficiently match properties between these nodes. Using fiber tractography available processing resources (which may be unimpaired) to methods to define the node/edge characteristics, which are the task demands. Consequently, they may overcommit pro-typically represented by ‘connectivity matrices,’ such a graph cessing resources to the coordination tasks without enhancing theoretical network analysis provides a novel way to explore performance. The neural mechanisms proposed by McAllister
topological and geometrical properties of brain networks, 

and colleagues (2001) may differ only in very subtle ways, and including (1) global network metrics, such as small-worldness


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Controls

TBI

improving diagnosis and treatment of patients with TBI. Future studies will address the effects of specific training interventions on brain structure, function, and connectivity, providing a window into neuroplasticity in TBI patients. These insights will provide a foundation for therapy to maximize sensorimo-
tor recovery after brain damage.

See also: *INTRODUCTION TO ACQUISITION METHODS: Diffusion MRI; Obtaining Quantitative Information from fMRI.*

Figure 1

Group differences in local efficiency. Left: controls. Right: TBI patients. Size of the ROIs (spheres and nodes) represents the value of local efficiency, and tube width of the lines (edges) represents the number of tracts.

References

(optimum between local specialization and global integration), and (2) regional nodal characteristics, such as the shortest path length (the average number of links between two nodes), clustering coefficient (the extent of interconnectivity among the neighbors of a specific node), and efficiency (how


Among others (Rubinov & Sporns, 2010). Although the young

Asikainen, I., Nybo, T., Muller, K., Sarna, S., & Kaste, M. (1999). Speed performance TBI patients showed an overall small-world topology (an opti-


A significant decrease of network connectivity was found.

Assaf, Y., & Basser, P. J. (2005). Composite hindered and restricted model of diffusion Specifically, young TBI patients displayed a significantly


Increased characteristic shortest path length and lower values


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diffusion tensor imaging for characterizing diffuse and focal white matter
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network perspective (Griffa et al., 2013). Finally, we showed


significant correlations between postural control performance

neuropsychological status at the time of hospital discharge. Developmental (assessed with the SOT test of the NeuroCom) on one hand and


network property metrics on the other hand within the TBI


group. Specifically, the decreased connectivity degree (a measure of density of the network) was significantly associated with


sure of density of the network) was significantly associated with


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Conclusion

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In this article, we have demonstrated deficits in gross and fine motor performances using instrumented tasks with emphasis

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represent a few of the possible options for imaging brain
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structure and function following TBI. This is an exciting
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time in neuroimaging, with ever-increasing possibilities for
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Upper-limb function in Australian children with traumatic brain injury: A controlled,


Document Outline

- Neural Correlates of Motor Deficits in Young Patients with Traumatic Brain Injury
  - Motor Deficits in Young Patients with Traumatic Brain Injury
  - Structural Integrity of the Brain and Its Relation to Motor Functioning in TBI
  - Brain Function and Compensatory Mechanisms in Young Brain-Injured Patients
  - Analyses of Structural and Functional Connectivity in Young Patients with TBI
  - Conclusion
  - References