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Deficits in complex visual information processing after mild TBI: Electrophysiological markers and vocational outcome prognosis

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Abstract

Primary objective: To evaluate low-level to complex information processing using visual electrophysiology and to examine the latter's prognostic value in regards to vocational outcome in persons having sustained a mild traumatic brain injury (mTBI).

Research design/methods: Event-related potentials (ERPs) were recorded to pattern-reversal, simple motion, texture segregation and cognitive *oddball* paradigms from 17 participants with symptomatic mTBI at onset of specialized clinical intervention and from 15 normal controls. The relationship between abnormal electrophysiology and post-intervention return to work status was also examined.

Main outcomes and results: Participants with mTBI showed a statistically significant ($p < 0.05$) amplitude reduction for cognitive ERPs and delayed latencies for texture ($p < 0.05$) and cognitive paradigms ($p < 0.005$) compared to controls. Furthermore, participants with mTBI presenting texture or cognitive ERP latency delays upon admission were at significantly ($p < 0.01$) greater risk of negative vocational outcome than mTBI participants with normal electrophysiology.

Conclusions: The findings suggest that individuals with symptomatic mTBI can present selective deficits in complex visual information processing that could interfere with vocational outcome. ERP paradigms such as those employed in this study thus show potential for evaluating outcome prognosis and merit further study.

Keywords: *Mild traumatic brain injury, electrophysiology, vision, cognition intervention, return to work*

Introduction

Traumatic brain injury (TBI) is the main cause of acquired brain damage in adults, with more than half of all cases resulting from motor vehicle accidents [1–3]. Lesion-producing mechanisms in TBI comprise acceleration–deceleration and rotational forces that induce a complex neurometabolic cascade including microscopic damage at neuronal, axonal and vascular levels [4, 5]. Mild TBI (mTBI) represent ~80–90% of annual emergency room TBI diagnoses [6]. It is estimated that up to 15% of mTBI cases can result in poor global functional outcome due to persisting symptomatology [7–11]. In industrialized countries, mTBI has been qualified as a major public health issue due to its incidence, estimated to be as high as 500/100 000 [12], its strong prevalence in young adults [6, 13] and because it can lead to long-term incapacities, hamper accomplishment of life habits, such as employment, and diminish quality of life, all at a high cost to society [14–16].

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Studies generally report good short-term global functional outcome in the majority of individuals having sustained a mTBI [17]. However, there is increasing evidence from animal [18, 19], as well as from human studies [7, 20–28], that information processing deficits do occur after mTBI and can persist beyond the expected recovery period of a few days/weeks to up to 3 months. This could be particularly true for mTBIs resulting from motor-vehicle accidents, where physical and acceleration–deceleration forces are greater than those implicated in other mTBIs, such as sports-related injuries, which have been the focus of much of the recent literature [10].

For detecting subtle structural brain damage caused by mTBI, Computerized Tomographic scanning has shown low sensitivity, whereas Magnetic Resonance Imaging has a greater detection probability (i.e. around 70%). But such methods do not provide data on cerebral function *per se* [29]. Brain imaging techniques such as Single-Photon Emission Computerized Tomography, Positron Emission Tomography and functional MRI, while contributory and promising, are invasive and costly, thus limiting their clinical application, and have yet to be established as reliable diagnostic or prognostic tools [30]. Furthermore, studies using standardized neuropsychological tests in symptomatic individuals with mTBI have also produced mixed results, with some yielding no identifiable neurocognitive deficits [29, 31, 32], while others show affected performances in various cognitive domains, particularly in terms of speed of processing [17, 33].

Event-related potentials (ERPs) have been studied in TBI because they represent a reproducible and less costly method to objectively and non-invasively evaluate different levels of information processing. For example, visual paradigms of graded complexity starting from those requiring simple visual analysis to more integrative ones can be used [25, 34–37]. Most visual electrophysiological studies conducted in individuals with symptomatic mTBI have looked at cognitive/decisional processes and generally showed alterations in amplitude, less reliably in latency, and also in behavioural response times for the corresponding P3 component [23, 26, 38–40].

More recently, specific and more complex stimuli have been utilized to generate ERPs associated with integrative visual processing such as texture segregation. The latter has been shown to reflect processes following primary analysis of visual input (contrast modulation) and necessary for object recognition [34, 41, 42]. In a previous study conducted with participants having sustained a TBI, the ERP evoked to texture segregation was investigated [25]. The latter has been shown to originate from VI and to reflect the integration of information from associative visual areas (V2 and V3) via intracortical retroaction circuits towards V1 [41, 43]. Significant latency delays were reported in participants with preserved low-level visual analysis and normal structural neuroimagery. This suggested that individuals with mTBI could present with dysfunctions in complex visuo-perceptual integration as evidenced with ERPs. Hence, the measures used were able to detect subtle deficits that remained silent with standard electrophysiology or neuroimagery. This finding was of particular importance, since post-TBI deficits in complex visual processing were previously shown to be strongly correlated with global outcome [2].

However, the relationship between electrophysiological deficits and functional outcome remains unclear. Because individuals with mTBI are now better identified and, where available, referred to outpatient programmes for clinical services when needed, it has become imperative to develop objective and sensitive clinical markers of information processing deficits, as this should permit rapid and accurate determination of specific functional deficits, quick referral for proper interventions and improved global functional outcomes [6, 13]. Therefore, the purpose of this study was to evaluate, using various ERP paradigms, visual and cognitive information processing in mTBI at the onset of specialized clinical intervention. It also assessed the prognostic value of these electrophysiological techniques in regards to vocational outcome following treatment.

Materials and methods

Participants

Visual and cognitive ERPs were recorded in 17 mTBI participants (seven males and 10 females) ranging from 17–57 years of age (mean 34.2, SD 11.2 years). All had sustained mTBI during a motor-vehicle accident and were symptomatic at the time of testing. Participant characteristics are presented in Table I. Symptomatology was self-reported and measured with the Rivermead Post-Concussion Symptoms Questionnaire [44], allowing for evaluation of number of symptoms (maximum of 16), as well as total symptom score (0: 'Not experienced', 1: 'No more of a problem', 2: 'Mild', 3: 'Moderate', 4: 'Severe', for a maximum of 64). Mean number of symptoms was 12.8 (SD 4.3) and mean total symptoms score was 37.8 (SD 16.2). All participants had been employed full-time before sustaining their mTBI. Participants were recruited upon their admission into the Outpatient Intervention Programme for Mild TBI at the Centre de Réadaptation Lucie-Bruneau in Montréal

Table I. mTBI participant characteristics, ERP results and vocational outcome.

					Symptomatology (Rivermead)			
MTBI subject #	Gender/Age (years)	GCS score/15	CT-scan or MRI finding	Time since injury (months)	Number of symptoms/16	Total score/64	Complex ERP latency delay, Yes or No	Return To Work, Yes or No
1	M/37	15	+	4	N/A	N/A	Y	N
2	M/24	14	+	3	14	44	N	Y
3	M/33	13	+	18	1	2	Y	N
4	M/34	13	−	2	16	51	N	N
5	F/33	14	+	20	15	43	N	Y
6	F/39	15	−	28	12	34	N	N
7	F/17	15	−	21	11	27	N	Y
8	F/51	15	−	2	16	53	Y	N
9	F/47	14	−	5	14	39	Y	Y
10	F/22	15	+	1	11	27	N	Y
11	F/25	15	−	6	14	49	N	Y
12	F/30	14	−	9	15	57	Y	N
13	M/57	14	+	9	12	24	Y	N
14	F/29	13	−	27	16	53	N	Y
15	F/23	14	−	6	5	9	Y	N
16	M/48	15	−	3	16	51	Y	N
17	M/33	14	−	12	16	42	Y	N

GCS: Glasgow Coma Scale; N/A: not available; +: presence of abnormality; −: no abnormality.

(Québec, Canada) [45]. They were evaluated between 1–28 months post-TBI (mean 10.4, SD 9.0 months).

TBI severity was obtained from medical files and verified as corresponding to the criteria proposed by the American Congress of Rehabilitation Medicine (ACRM) and the WHO Task Force on MTBI [6, 46]. Inclusion criteria for mild TBI were a Glasgow Coma Scale (GCS) score of 13–15/15 and post-traumatic amnesia (PTA) duration of less than 60 minutes. The following data were also obtained from medical files of participants with mTBI: gender, age, presence of CT-scan or MRI abnormalities and return to work status at end of treatment (documented from medical files at the end of the study). Hence, at the time of electrophysiological testing and analysis (i.e. on admission), vocational outcome of the participants with mTBI was not known. ERPs were also obtained in 15 normal control participants (seven males and eight females) ranging in age from 21–47 years (mean 29.1, SD 7.3 years) and employed full-time at the time of testing.

All participants had best-corrected visual acuity of 20/20 or better, they had no visual pathology as established by an ophthalmological examination and they had no previous or present psychiatric illness or substance abuse problems. Furthermore, normal control participants had never sustained head trauma. The research followed the Tenets of the declaration of Helsinki and was approved by the Centre for Interdisciplinary Research in Rehabilitation's ethical committee. Informed consent was obtained from all participants after the nature and possible consequences of the study had been fully explained. All participants received a small financial compensation for their participation in this study.

Main outcome measure

Post-mTBI return to work status, more specifically the ability to return to an active vocational life at the end of interventions, was the outcome measure used in the present study. An active vocational life was defined as working, for 21 hours or more, in gainful employment, searching for gainful employment or studying in a programme leading to gainful employment. Individuals participating in some non-gainful or volunteer activities were not considered as returned to work.

Electrophysiology

Signals were recorded from either of three scalp locations (Oz, O1-O2 or Pz) using active gold-cup Grass electrodes following the International Society of Clinical Electrophysiology in Vision (ISCEV) standards, in keeping with the 10/20 system [47]. An electrode placed on the forehead served as reference and the ground was attached to the earlobe. Signals were low pass digitally filtered at 40 Hz. Electrode impedance was maintained under 5 kΩ (Grass impedance meter, model E2M5). Stimuli were presented using a Macintosh G4 computer with a resolution of 800 × 600 pixels at a

frame rate of 75 Hz. They were generated by the EP-2000 Freiburg evoked potentials system and viewed on a ViewSonic monitor installed 1.14 m from the participant. The screen covered 19° horizontal ×18° vertical and luminance was kept constant at 45 cd m^{-2}.

All participants were tested using four separate paradigms of increasing complexity in order to acquire the following ERPs: pattern-reversal (Oz electrode), simple motion (mean of O1 and O2 electrodes), texture segregation defined by motion (Oz electrode) and cognitive *oddball* (Pz electrode) with corresponding behavioural response times (visuo-motor reaction time). To maintain a high level of attention, participants were asked to fixate a dot in the centre of the screen (except for the cognitive ERP condition) and to signal the appearance of a number in the centre of the dot. One hundred sweeps were recorded and grand averaged online for each condition, except for the cognitive *oddball* paradigm, which consisted of a total of 280 trials. The complete recording session with electrode installation lasted ∼60 minutes and included frequent pauses to avoid fatigue.

Stimulus characteristics for the different paradigms were the following (see Figure 1): (a) pattern reversal: black/white checks of 0.8° in spatial frequency, 98% contrast, reversal rate of 2 Hz; (b) simple motion: contracting/expanding target with components of 0.7° in spatial frequency, 20% contrast, 1 Hz temporal frequency; (c) texture segregation: bright squares of 0.1° on a dark background with correlated motion of all squares in the same direction, left or right (homogeneous condition) or motion, either left or right, of half of the squares in a checkerboard arrangement (mixed condition), 30% contrast, 1 Hz displacement rate; (d) cognitive *oddball*: simple checkerboard configuration (in order to evaluate a further level of visual information processing, but without requiring high-level attentional resources as this was not the aim of this study) made up of either of 0.5° checks (appearing 80% of the time, frequent condition) or 1.5° checks (20% of trials, rare condition), 98% contrast, 80 ms stimulus duration time with random inter-stimulus intervals between 1–1.4 s, participants instructed to press a response button with their index finger in response to the rare stimuli, to which reaction times were also recorded.

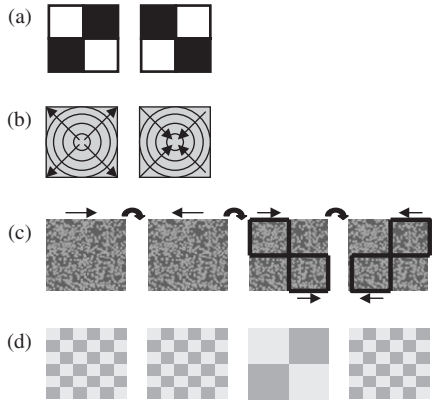

Figure 1. ERP stimuli. Stimuli used to obtain ERPs: (a) pattern reversal; (b) simple motion; (c) texture segregation; (d) cognitive *oddball*.

Waveform analysis

Analysis was done only on artifact-free electrophysiological trials. Signals contaminated by blinks or any artifacts were automatically rejected by the recording system and repeated in order to obtain the required number of successful trials for grand averaging. For the pattern-reversal condition, the peak of interest was P1 (major positive component peaking at ∼100 ms post-stimulus). For the simple motion condition, the largest N2 peak (negative deflection at ∼160 ms) of the two lateral electrode sites (O1 or O2) was retained for analysis [48]. The component specific to texture segregation was the negative deflection around 150–170 ms and was obtained by subtracting the homogeneous responses from the mixed ones and then divided by 2 (detailed procedure and rationale published elsewhere [25, 34]). The above peaks of interest were analysed in amplitude (from peak-to-peak, in μV) and latency (from start of stimulation to the peak, in ms).

For cognitive ERPs, the component of interest was the P3 (positive peak culminating at ∼300 ms) obtained to the rare condition. For the P3 peak, a specific time windows was selected to include the totality of the positive wave, ∼200–700 ms, and the latency was determined as being the time required to reach 50% of the summed activity in the window, whereas amplitude was calculated at that specific latency with respect to baseline [35]. For each ERP condition, group amplitude and latency mean and standard deviation were calculated. Mean and standard deviation of reaction times obtained in response to the rare stimuli in the *oddball* paradigm were also calculated, with previous elimination of responses possibly resulting from anticipation or contaminated by fatigue (i.e. response times faster than 150 ms or slower than 1500 ms discarded from analysis).

Statistical analysis

Because separate paradigms were used to obtain the different components studied, which represent different visual processes, Student *t*-tests were

performed to compare the group with mTBI with the normal control group on each electrophysiological condition. Assumptions of normality of distribution (NormCheck, $68\% \pm 1$ SD, $95\% \pm 2$ SD, $99\% \pm 3$ SD rule) and homogeneity of variance (F_{max}, $p > 0.05$) were met for all analyses. The relationship between the presence of electrophysiological abnormalities at admission and return to work status at end of intervention was determined using simple logistic regression analysis and chi-square testing [49].

Results

Electrophysiology and reaction time

Figure 2 shows grand averaged group mean ERP responses for (a) pattern-reversal, (b) simple motion, (c) texture segregation and (d) cognitive *oddball* paradigms. The peaks of interest are identified and compared between the mTBI and normal control groups. The morphology of the responses is similar for the two groups and there appears to be larger amplitude and/or latency differences between groups as stimulus complexity increases.

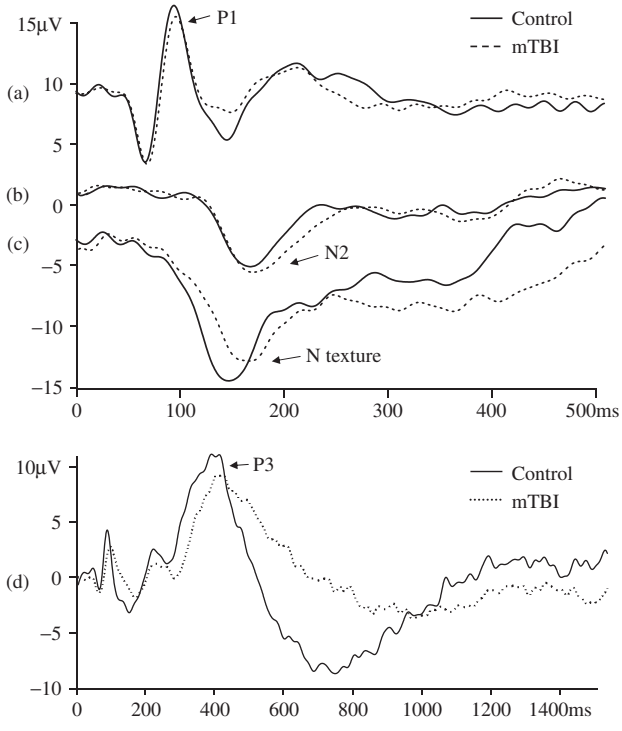

Figure 2. Averaged ERP waveforms obtained to each paradigm. Grand averaged ERP responses obtained to the different conditions of grading complexity: (a) pattern reversal; (b) simple motion; (c) texture segregation; (d) cognitive *oddball*. Mild TBI group: dashed lines; control group: solid lines. Vertical calibrations: top for (a–c); bottom for (d).

Figure 3 shows, in histogram format, the ERP amplitude (a) and latency (b) results for the four paradigms used. There are no statistically significant amplitude differences between the mTBI and normal control groups for pattern-reversal ($t = 0.69$, $p > 0.05$), simple motion ($t = 0.96$, $p > 0.05$) and texture paradigms ($t = 1.02$, $p > 0.05$). The participants with mTBI do, in contrast, show a statistically significant ($t = 2.11$, $p < 0.05$, 95% CI 0.23, 12.59) cognitive ERP amplitude reduction when compared to controls. Latency analysis also yields differences between the two groups, mTBI participants showing statistically significant timing delays for the two most complex conditions, texture segregation ($t = 2.68$, $p < 0.05$, 95% CI 4.55, 33.45) and cognitive ERPs ($t = 3.55$, $p < 0.005$, 95% CI 25.76, 95.42). No statistically significant latency differences are found for pattern-reversal ($t = 1.24$, $p > 0.05$) or motion paradigms ($t = 1.53$, $p > 0.05$). Furthermore, mTBI participants show a slower reaction time than normal controls, but this difference does not quite reach statistical significance ($t = 1.95$, $p > 0.05$).

Thus, ERP responses in mTBI are affected only for complex stimulus paradigms (texture and/or cognitive) and in particular with respect to latency. In contrast, with the simpler stimuli (pattern-reversal

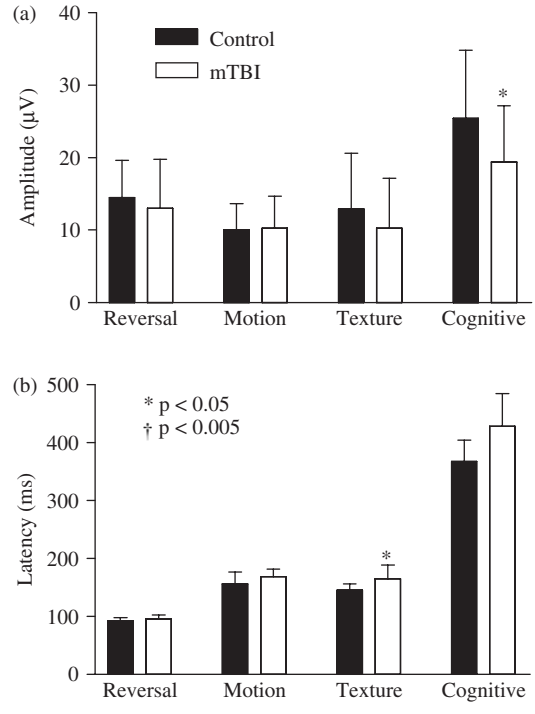

Figure 3. Mean ERP amplitudes and latencies. Mean ERP results (±1SD) obtained, in the different conditions, from normal control and mTBI groups for: (a) amplitude; (b) latency. * and † = significant differences between participants with mTBI and normal controls.

Table II. Association between return to work status and electrophysiological abnormalities.

	Return to work		
Abnormal ERPs	Yes	No	Total
Yes	1	8	9
No	6	2	8
Total	7	10	17

Note: OR = 24.0, 95% CI 1.74, 330.8; Likelihood ratio $\chi^2 = 7.8$, $p < 0.01$.

and simple motion), no significant differences are observed between the two groups.

Complex visual information processing deficits and vocational outcome

Electrophysiological results indicate that the most sensitive indices for discriminating between participants with mTBI and normal controls are the latency of complex ERPs. Consequently, the latter were retained for prediction analyses in regards to return to employment. Participants with mTBI whose texture and/or cognitive ERP latency was 2+ SD from normal control mean (a typical cut-off used in clinical electrophysiology [37]) were identified as having abnormal electrophysiology. Table II shows the classification results according to this criterion and to vocational outcome. Of all participants with mTBI, 41.2% were able to return to active work-related activities following rehabilitation interventions, whereas the remaining individuals were not. Eighty per cent of the latter had latency abnormalities for complex ERPs, while those able to return to employment had a latency abnormality rate of 14.3%. Statistical analysis shows that individuals with mTBI presenting texture or cognitive ERP latency delays upon admission are at significantly greater risk of negative vocational outcome than those with normal electrophysiology (OR = 24.0, 95% CI 1.74, 330.8; Likelihood ratio $\chi^2 = 7.8$, $p < 0.01$).

Hence, the overall percentage of cases correctly classified based on the presence or absence of electrophysiological latency abnormalities upon admission is 83.4% (i.e. 14/17 cases). The positive predictive value (percentage of individuals with normal ERPs having returned to active vocational activities following interventions) is 75.0%, whereas the negative predictive value (percentage of individuals with abnormal electrophysiology who did not return to work) is 88.9%. Furthermore, there was no correlation between time post-injury or age and vocational outcome as determined by ERP latency ($r = 0.14$, $r = -0.39$, $p > 0.05$).

Discussion

Electrophysiological markers

This study is the first to evaluate visual information processing in symptomatic mTBI using different levels of stimulus complexity and its relationship with vocational outcome. Participants with mTBI showed deficits in complex information processing (i.e. texture segregation, cognitive *oddball* paradigms), while they were not different from normal controls for lower-level stimuli (i.e. pattern-reversal, simple motion). Dysfunction in higher-level processes is in line with previous findings in ERP studies attempting to evaluate the quality and speed of information processing following mTBI. More specifically, it was previously evidenced, in individuals with mTBI and normal structural neurorimagery, latency abnormalities for texture segregation ERP paradigms in the presence of preserved low-level visual analysis [25]. Also, cognitive ERP studies conducted with concussed athletes or participants with mTBI showed attenuated cognitive P3 amplitudes in symptomatic participants [23, 26, 50, 51]. Other studies have found longer cognitive ERP latencies in symptomatic mTBI [38] and in athletes having sustained multiple concussions [52]. Furthermore, slowed response times have been previously shown in concussed symptomatic athletes when compared to asymptomatic athletes and normal controls [50], as well as in children having sustained a mTBI [22]. In the present study, the reaction time increase evidenced in mTBI participants was on the cusp of statistical significance, but difficult to interpret in light of the small sample size.

The findings of higher-level integrative visual ERP latency abnormalities (i.e. texture) and timing deficits in the cognitive domain (i.e. cognitive *oddball*) are not surprising given that visual information is processed, at least in part, hierarchically, being analysed first at a low-level and then transferred to a superior one for subsequent processing. More complex visual processes have been shown to be sensitive following an insult to or alterations in cerebral areas involved in visual processing. For example, second-order visual processing can be impaired in the presence of spared first-order processing after a cerebro-vascular insult [53], in developmental pathologies such as autism [54] and during the normal ageing process [55]. Furthermore, recent preliminary psychophysical evidence obtained in children after mTBI also pointed to affected complex visual perceptual deficits in the presence of spared first-order analysis [56].

Studies have demonstrated that retroaction connections between V1 and higher-order visual areas (V2/V3) are necessary for second order (i.e. higher-level) stimulus processing [43, 57]. Processing of

first order (i.e. low-level) stimuli would depend mainly on V1 [54]. Cognitive ERPs (i.e. P3 component) originate from more anterior areas of the brain involving complex integrative antero–posterior cortical processes [37]. Consequently, their altered state could be interpreted as an indicator of abnormal processing between cerebral areas.

In the present study, both amplitudes as well as timing measures were affected for higher level processing, but effects were stronger for timing deficits. The latter suggests not only compromised quality of information processing, but even more so delayed processing speed [35] in the participants with mTBI. Furthermore, these deficits are present not only in the cognitive-attentional domain (i.e. *oddball* paradigm), an aspect previously documented by others [11, 24, 26, 27], but also for integrative visual processes (i.e. texture segregation). Hence, this alteration in visuo-integrative mechanisms could contribute to the visuo-motor and visuo-attentional abnormalities previously found in this clinical population.

A justification of the deficits evidenced in this study can be found in the neuropathology of mTBI. Traditional models of head injury have shown that acceleration, deceleration and rotational forces at the time of the trauma produce micro tears, damaging cellular bodies and cerebral axons [4, 5, 58, 59]. This model of axonal injury and its functional consequences are supported by autopsy results in humans as well as by experimental mTBI in animal models [18]. Recent studies have shown the occurrence of changes at the axonal transport level following mTBI [60, 61]. The regions that are most sensitive to these mechanisms are the frontal and occipital lobes, with compression of frontal regions and stretching in posterior regions following mild acceleration [61–64]. It is therefore not surprising that more complex visual paradigms, such as those measuring integrative visual processes and cognitive ERPs, which require higher-level processing, are affected in symptomatic mTBI [38].

Speed of processing and vocational outcome

Timing deficits for complex paradigms were the most evident in participants with mTBI. Such deficits could have a direct impact on the ability to pursue or resume complex life habits such as work, for example resulting in slowed speed of task performance, misinterpretation of visual information, quantity of work below competitive levels, etc. This is, in fact, suggested by the finding that ERP latency abnormality upon admission represented significant predictor of inability to return to employment-related activities at the end of interventions. Return to work is one of the life habits most often affected after mTBI and is a good reflection of social participation [10, 31, 65]. Factors like gender, education, history of anterior neurological or psychiatric problems, lesion-production mechanisms and neuropsychological tests scores [10, 65, 66] have been studied to try to identify predictors of vocational outcome in mTBI, but no consensus has been established as to their predictive abilities. More recently, it was reported that other factors such as age (i.e. over 40) and number of subjective symptoms (i.e. six or more) contributed significantly to the prediction of return to work status in a symptomatic mTBI population [15].

The present study showed significantly delayed complex information processing in symptomatic individuals with mTBI, on the basis of which 83.4% of participants were accurately classified according to vocational outcome. This indicates that the latency of complex ERP paradigms, such as those employed in this study, represent good markers of post-mTBI information processing deficits. Such functional markers thus show potential for evaluating global outcome prognosis and are of particular relevance for attempting to objectify dysfunction relative to symptom reporting, which is of a subjective nature [8, 9, 11]. In fact, in regards to mTBI, the validity of self-reported symptoms remains controversial, particularly because similar symptomatology has been shown in individuals without brain damage [67]. Nonetheless, even if some participants presented symptom magnification, it would not have affected the findings, since they are based on a relatively objective measure (i.e. ERPs) and not on symptom reporting.

Furthermore, decisions for return to activity (work, school, play, etc.) in individuals having sustained mTBI are usually based on resolution of symptoms [68–70]. However, even if symptoms are used as a recovery cue of the injured brain, functional deficits identified through ERPs and response times have been evidenced despite the resolution of post-concussion symptoms [23, 71]. Thus, the addition of complex ERPs targeting visual integration processes, as well as the cognitive domain, to clinical indices such as symptomatology is warranted in order to identify deficits in information processing that could remain silent with other methods (i.e. neuroradiology, neuropsychological testing, etc.).

The results of the present study are also particularly relevant in regards to intervention. Mild TBI can present with a complex combination of clinical problems for which outcome prediction and treatment efforts can be difficult [72]. In particular, it has

been evidenced that mTBI individuals with extracranial injuries have poorer functional outcomes [73]. This aspect has not been directly studied here, but such injuries could be more prevalent in mTBIs resulting from motor-vehicle accidents, as was the case for this mTBI cohort, which showed significant deficits in the processing speed of complex information. Hence, complex ERPs can permit the assessment of severity of such functional deficits and could be used to justify targeted interventions for individuals with mTBI.

Finally, even in the light of the clinically and statistically significant findings, the limited sample size, variability in post-trauma evaluation times and lack of use of other outcome measures do represent shortcomings of the present study. These aspects need to be addressed in a larger mTBI population in order to refine one's understanding of the relationships between complex ERP measures and clinical presentation and to transform these into useful, valid clinical tools.

Conclusion

This study has demonstrated that symptomatic individuals with mTBI present deficits in complex visual information processing and that speed of processing as assessed by complex visual ERPs upon admission represent a good prognostic indicator in regards to vocational outcome. These electrophysiological measures show promising potential for evaluating global outcome prognosis and assessing cerebral recovery. Furthermore, the prompt identification of such functional deficits can justify early implementation of specific intervention strategies to diminish the impacts of information processing deficits, with the aim of reducing the societal and personal costs of post-mTBI consequences.

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